Corrosion

58
YEARS OF SERVICE
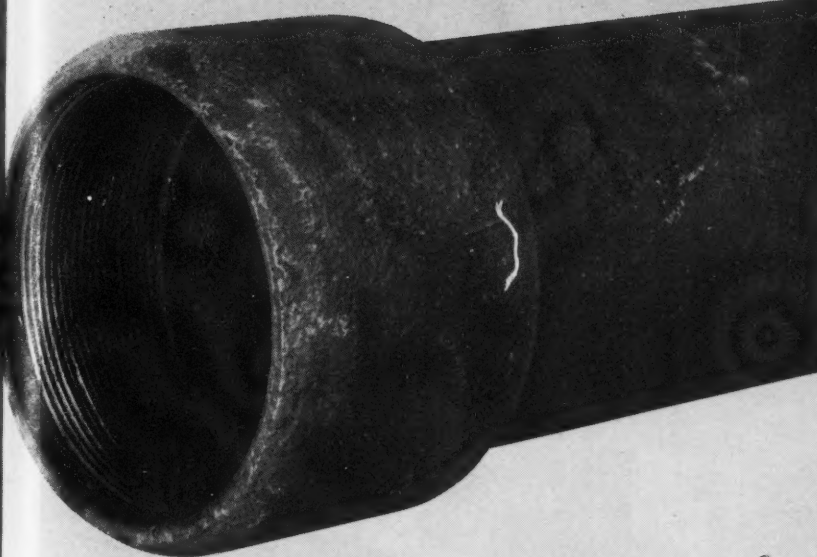
Longitudinal photomicrograph S-64-2 (100x) shows a typical area—parallel to rolling—of the microstructure observed in the subject 5-inch wrought iron pipe.

Metallurgical Report 6628—Underground Oil Line*

This report deals with the metallurgical examination of a length of 5-inch wrought iron pipe, submitted to our laboratory for investigation and comment.

The sample submitted has been in service 58 years, yet found to be in excellent condition. Note that the scale is tightly adherent to the surface of the pipe.

ROCKWELL HARDNESS

A cross-sectional ring was prepared for hardness determination. Hardness values taken around the cross-sectional ring indicated a B66 hardness typical for wrought iron pipe and showed that the strength and ductility were likewise normal.

CHEMICAL ANALYSIS

Carbon—.018%; Manganese—.040%; Phosphorus —.236%; Sulphur—.019%; Silicon—.186%; Iron Silicate—3.54%.

SUMMARY

Results of the laboratory examination serve as positive identification of the subject sample as wrought iron. The excellent state of preservation of this sample after more than a half-century of service is indicative of wrought iron's longevity in corrosive service. A. M. Byers Company, Clark Building, Pittsburgh 22, Pennsylvania.

*Name of actual installation given on request.

Write for free cloth-bound book, *Wrought Iron: Its Manufacture, Characteristics and Applications.*

BYERS
WROUGHT IRON

CONTENTS

TECHNICAL SECTION

CONTENTS

(Continued From Page 3)

13th ANNUAL CONFERENCE REPORT

GENERAL NEWS

Scheduled for Publication in May

In the Technical Section: Evaluation of Cooling Water Corrosion Inhibitors. A Report of NACE T-5C-1 on its first series of interplant tests. Numerous other technical papers.

News Section: More information about what happened at St. Louis and developments in the programs for the six regional meetings scheduled by NACE during the remainder of 1957.
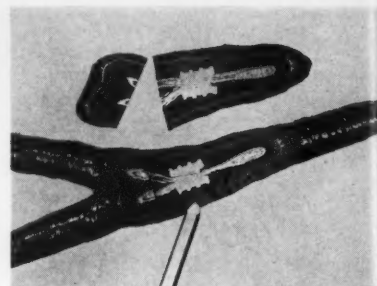
THIS MONTH'S COVER—The tailor made field splice shown above has been impregnated with epoxy resins using a technique, materials and tools developed by Minnesota Mining & Manufacturing Co., St. Paul, Minn. The splice is said to be moisture proof, void free and with high dielectric strength.

☆

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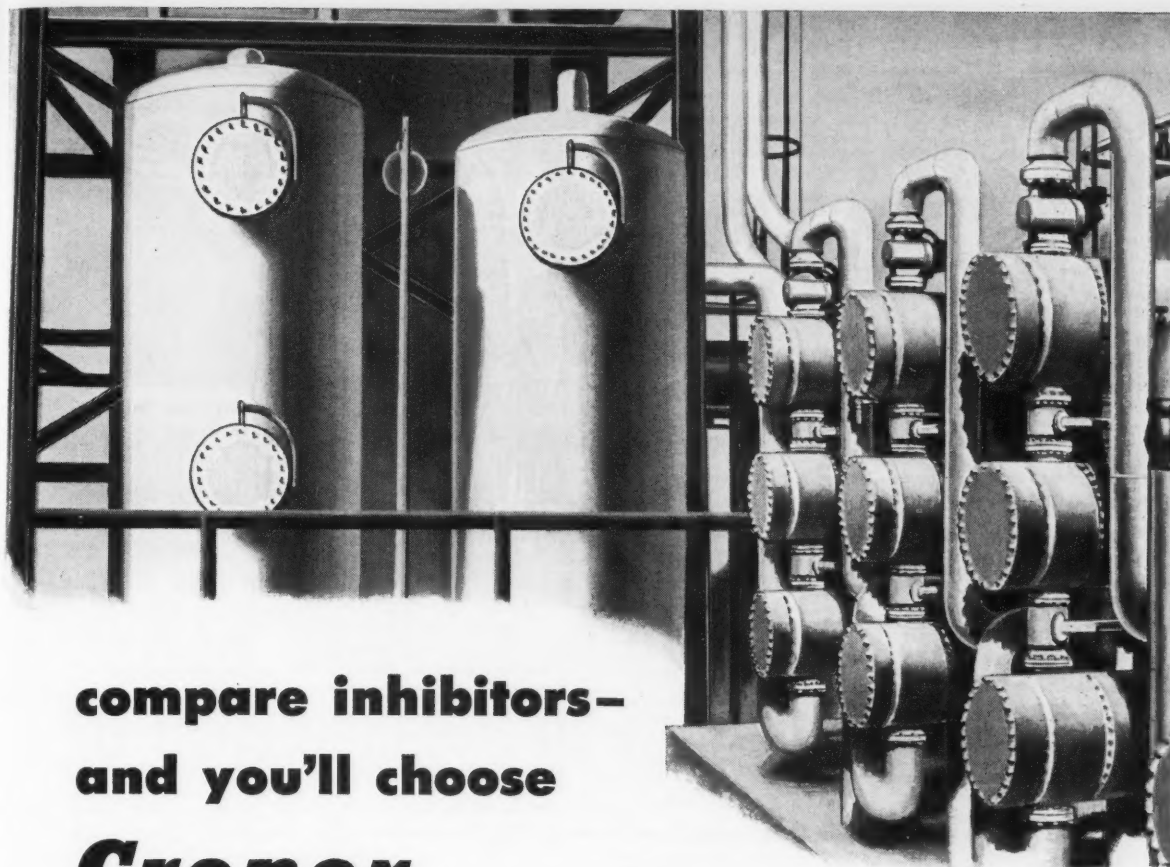J. F. Klim, Chairman; New York Telephone Company, 158 State Street, Albany, New York

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PAPERS SCHEDULED FOR PUBLICATION

Corrosion by Low-Pressure Geothermal Steam by T. Marshall and A. J. Hugill.

Probems of Corrosion in Large Steam Generating Stations by T. J. Finnegan.

Testing Methods and Corrosion Control Measures for Buried Telephone Cables by Daniel R. Werner.

Prevention of Corrosion in Naval Aircraft by S. L. Chisholm and N. N. Rudd.

Some Aspects of the Corrosion Processes of

Iron, Copper and Aluminium in Ethylene Glycol Cooling Fluids by P. F. Thompson and K. F. Lorking.

Control of Corrosion With Zinc Coatings by J. L. Kimberley.

Properties and Performance of Reinforced Polyester Plastics in the Chemical Industry by R. E. Gackenbach and D. G. Estey.

Corrosion by Differential Aeration and Passivity of Zinc by G. Bianchi.

THE NATIONAL ASSOCIATION OF CORROSION ENGINEERS

is a non-profit, scientific and research association of individuals and companies concerned with corrosion or interested in it, whose objects are:

(a) To promote the prevention of corrosion, thereby curtailing economic waste and conserving natural resources.

(a) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

(f) To contribute to industrial and public safety by promoting the prevention of corrosion as a cause of accidents.

(g) To foster cooperation between individual operators of metallic plant and structures in the joint solution of common corrosion problems.

(h) To invite a wide diversity of memberships, thereby insuring reciprocal benefits between industries and governmental groups as well as between individuals and corporations.

It is an incorporated association without capital stock, chartered under the laws of Texas. Its affairs are governed by a Board of Directors, elected by the general membership. Officers and elected directors are nominated by a nominating committee in accordance with the articles of organization. Election is by the membership.

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Topic of the Month

Automotive Industries Back Corrosion Test Program with Field Surveys

*By LEONARD C. ROWE**

THE MOST unique corrosion test area known to man is that found on the surface of the earth. Corrosive conditions vary from one location to another and from day to day in the same location with an assist by man-produced contaminants.

These conditions offer a challenge to automotive personnel in their attempt to prevent exterior metal corrosion on the automobile. It is expected that the average automobile will be exposed to variable hot to cold temperatures, wet to dry air, water to snow, dust to gravel, acid to basic materials, and ultraviolet to infrared light. With the addition of a few metal ions and some salt the setting is obtained for corrosive conditions which must be contained.

It would be extremely difficult to simulate all these conditions in any one laboratory test or to find them at one field site. Nevertheless, certain testing procedures had to be adopted to assist in quality control and research on protective coatings, electroplated coatings, metal composition, and in many other areas. For this reason the automotive industry has taken active participation in sponsoring and using accelerated tests.

The salt spray and humidity cabinet tests have been used extensively for many years to gain comparative information on protective coatings. This type of test serves only as the initial step in the overall test procedure. Along with other laboratory tests, these tests tend to separate the poor materials from the good. Through the years a background of information has been accumulated which has been helpful in making further progress.

Accelerated Test

The need for a more accelerated test for production control has encouraged the automotive industry and other groups to participate in initiating changes in the present tests. One such test is the acetic acid modification of the salt spray. Consideration is being given to obtaining greater acceleration by the

addition of certain metal ions to the base solution. Another approach has been made by cooperative work with the American Electroplaters Society which studied the 'Corrodkote' test for plated parts. The validity of these types of tests may be in question until the outcome is verified by service experience. It may be said, however, that these tests tend to spark further development work and enforce more careful surveillance in the application of protective coatings by techniques which are known to be good.

The automotive industry does not rely alone on the static type tests. In addition they have explored the alternate exposure type. The cyclic humidity type test has been of measureable assistance in the study of body steel corrosion. Other tests have been developed for evaluating painted panels by simulating alternate exposure to dew and sunlight. The results of these tests have been compared with those found at field test sites which are located in various parts of the country. Field test sites may be considered as laboratory tests which take advantage of nature's variable conditions in one area. Many of the results obtained at these sites have verified first thinking which had been based on laboratory tests.

Use of IBM Cards

It has been recognized for some time that to determine the full effect of field conditions, observations must be made directly on the automobile in service use. Teams of observers, composed of representatives from various phases of activity, make yearly surveys of several thousands of automobiles in different areas of the country. The extent and degree of inspection is clearly shown by the IBM cards in Figure 1. One card represents the inspection of plated parts in which the parts are rated numerically as to degree of failure. The other card represents the inspection of painted parts in which the type and location of failure is noted. The use of IBM cards has assisted materially in obtaining rapid information from a vast amount of data. The results indicate

* Research Staff, General Motors Corp., Detroit, Michigan.

Figure 1—IBM cards used for field survey of plated and painted automotive parts.

strong or weak points in a particular protective system. Of equal importance is the fact that they tend to confirm or deny information which has been obtained from accelerated and field site tests.

This progression in test procedures has lead to better corrosion resistance for present day automobiles. It has lead to a decline in the penetrating type of corrosion failure which formerly was evident in fender welts, rocker panels, gravel deflectors, and other areas. In comparing the improvements in corrosion resistance for the modern automobile from an appearance viewpoint, one must be concerned with the change in corrosive conditions brought about by air pollutants, driver habits, traffic conditions, and other factors. A more recent example where the field survey will play an important part is in the present increased use of light metals. A basic acceptance has been obtained through preliminary testing, but final acceptance can only be based upon performance in service as indicated by survey.

Corrosion Mechanisms in the Plain Can*

By E. L. KOEHLER and C. M. CANONICO

Introduction

THERE ARE a great number of food products packed in cans, and each appears to be somewhat of a separate and distinct entity from a corrosion standpoint. Moreover the corrosive nature of even a single specific product is subject to wide variation, being a function of the region and the season in which it is grown. The corrosion resistance of tin plate is not a property which can be characterized by any one single index. Instead it is dependent upon the interrelationship of the characteristics of the can and the product packed therein.

The present work concerns itself only with the corrosion resistance of plain (not inside enamelled) cans packed with food products in which tin sacrificially protects steel. More specifically, it deals with corrosion by prune juice and peaches. The type of corrosion failure commonly encountered with such food products is known as "hydrogen swell." As a result of the corrosion processes occurring within the can, hydrogen gas is evolved. This gas accumulates, builds up a pressure, and ultimately causes the ends of the can to bulge out. Such a can is unsaleable because bulged ends also may be an indication of food spoilage.

The pack test is the principal tool which the can industry has used in the development of today's containers. It involves packing the cans with the product in question and storing until failure occurs. This is a performance test and is never likely to be displaced. It has, however, certain shortcomings. For example, it is difficult to use the pack test in obtaining fundamental information. Of greater practical importance is the fact that considerable testing time is required which means that the test cannot be used to indicate in advance how satisfactory a particular lot of tin plate may be. Empirical, short-time tests have been proposed from time to time to meet this deficiency. In general, there is no fundamental basis for tests of this type because test conditions are far removed from conditions existing in a can. They can be of value only when they have been demonstrated to give results which correlate with pack tests.

Current thinking recognizes corrosion resistance to be the end result of a complexity of factors rather than a single factor in itself. The currently used rate-of-pickling test and iron solution test were proposed to evaluate such individual specific factors which contribute to can corrosion.[1,2] Another empirical test recently proposed has not yet been confirmed by pack data.[3] Other short time tests have by this time been abandoned or supplanted.

In most food products, tin is anodic to steel and

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Abstract

A study was made of the various factors involved in the corrosion of plain tin cans containing fruit products. Results of tests conducted to determine the corrosive effects of prune juice and peaches on tin and steel are reported. Data include such items as amount of hydrogen evolved, amounts of tin and steel dissolved, potential relationships, protective currents and polarization characteristics of coupled tin and steel elements.

The shelf life of a plain tin can containing a fruit product such as prune juice is visualized as being made up of three distinct parts. In the first period the steel base is virtually completely covered with tin and the corrosion process occurring is solution of tin concurrently with reduction of depolarizers in the food product on the tin surface. In the second period, a significant amount of steel base is exposed and the corrosion processes are those of the tin-steel couple. It is significant that in this period not only is the steel base protected by the tin, but the rate of hydrogen evolution per unit area of steel base exposed is markedly reduced by the tin coating. This is not due to the inhibiting effect of dissolved tin but to another mechanism. In the third period, the can is completely detinned and attack is on the steel base alone. The life of the can is largely determined before this period.   7.5.2

sacrificially protects it. This has been attributed to the tendency for tin to form stable complex ions with the food acid anions,[4] the high hydrogen overvoltage of tin[5] and other factors.[6]

Much basic information has, of course, resulted from pack tests.[7] Such information, however, has not

in itself yielded a coherent picture of can corrosion mechanisms. Work in citric acid and other food acids has provided valuable information about corrosion processes;[8,9] however, such tests have not been demonstrated as being satisfactory to evaluate tin plate to be used in cans. There is considerable doubt that the corrosion mechanisms in such media correspond to those in food products in all respects.

Vaurio[10] made test ends of the tin plate in question and double-seamed these unenamelled ends to full enamel-lined cans. Tests also were made using various types of tin-steel couples including a tin wire grid on a steel black plate can end. Where desired, the amount of hydrogen evolved in the can was followed by measuring deflections of the can end with a dial gauge. While the results of these tests are of considerable interest, even here the test information obtained was not as complete as would be desired.

Scope of Experimental Program

The test methods used here were designed to get maximum information by permitting accurate measurements of hydrogen evolution, the amounts of tin and steel dissolved, potential relationships, protective currents, and polarization characteristics of coupled tin and steel elements. The test apparatus used in this work has been described in an earlier publication.[9] Hydrogen volume and weight loss relationships were determined in all-glass cells of approximately 300 cc volume with attached burettes for measuring the hydrogen gas. To measure the potential and current relationships, a different style of cell was used. This cell was bridged to a reference electrode and provided for external coupling of the tin and steel so that they could be uncoupled as desired for purposes of making measurements.

The steel specimens used were 6 cm × 4 cm (48 sq cm surface area) both for tests on black plate and for tests on black plate coupled to tin. These specimens were electrocleaned in sodium orthosilicate solution and rinsed prior to laboratory annealing. This provided a clean, bright surface which was not touched prior to testing.

The tin anodes used were approximately 0.145 inch thick and were cut into 3.5 cm squares (24.5 sq cm surface area). Ordinarily, only one anode was coupled to the steel specimen, although sometimes in the case of peaches, anodes were used on both sides of the steel specimen. Prior to use the tin specimens were electrocleaned and treated for 5 minutes in cold, concentrated hydrochloric acid solution.

In making tests on tin plate, the specimen size was identical with that of the black plate specimens. These specimens also were electrocleaned prior to testing. In tin plate tests the specimen edges were stopped off with a phenolic can enamel. This was found to be unnecessary for the tests on the untinned steel black plate whether coupled or uncoupled. The tin used was commercial grade A longhorn tin and the same lot was used throughout the test work. The steels used were from four different heats. Check analyses for these steels are given in Table 1.

The test media used were prune juice and liquidized peaches with all test work being conducted

under air-free conditions. One brand of commercial bottled prune juice was used throughout. The juice normally was found to be quite reproducible in its characteristics, although occasionally portions were encountered in which the corrosion behavior was far from normal. Tests always were made comparative to material of known behavior so that such abnormalities could be detected. This was encountered only occasionally and such results were discarded.

In other tests one brand of canned freestone peaches was used throughout. In preparing the test medium, half of the peaches in each can together with all of the juice therein were liquidized in a blender so that the medium could pass through the glass tubing in the test cells. Such liquidizing was done in a nitrogen atmosphere. This was followed by boiling under vacuum to remove gases from the product.

The previously mentioned rate-of-pickling test detects a condition in the steel base known as "pickle lag." This is detected by determining the rate of corrosion of the steel base plate in 6 N hydrochloric acid at 90 C. A steel exhibiting an incubation period in which the rate of corrosion is lower than the final, constant, rate is said to possess a pickle lag. This empirical test reflects a condition in the steel surface layers which is characterized by the formation of oxides in the grain boundaries.[2] The origin of this condition has been found to be associated with the composition of the annealing gases; evidently it comes about with the formation of gases which are oxidizing to the grain boundaries but reducing to the grain centers.

Steels with a pickle lag have been demonstrated to have poor corrosion performance in prune pack tests. It has been found possible to produce a pickle lag in the laboratory by annealing the steel base plate in a wet hydrogen atmosphere; a dry hydrogen anneal produces a steel with no pickle lag. The steels used in this work were laboratory annealed in wet or dry hydrogen to include this variable in the test work.

Pickle lag is only one factor affecting the corrosion resistance of the base plate. There are a number of other factors which are not specifically considered in this work.

Corrosion of Tin

In citric acid solution in the absence of air, tin is unattacked. This is because of the high hydrogen overvoltage of tin which prevents reduction of hydrogen ions. Since no alternate reducible material is present, the tin is not oxidized. In the presence of air, tin is attacked, tin being oxidized concurrently with an equivalent reduction of oxygen.

Inside a tin can, conditions must be considered as air-free. Corrosion rates were determined for tin specimens in air-free prune juice at both 140 F (60 C)

TABLE 1—Chemical Analyses of Test Steels

Steel	C	Mn	P	S	Si	Cu	Al	Ni	Cr	Mo
W	.073	.40	.009	.032	<.002	<.04	<.006	<.02	<.01	<.02
X	.070	.30	.013	.042	<.002	<.04	<.006	<.02	<.01	<.02
Y	.056	.35	.013	.047	<.002	<.04	<.006	<.02	<.01	<.02
Z	.074	.38	.010	.033	<.002	<.04	<.006	<.02	<.01	<.02
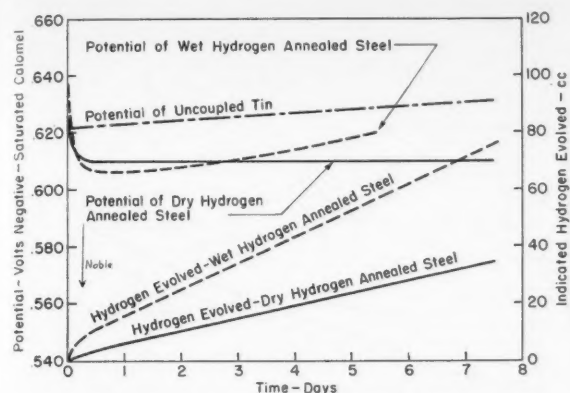
Figure 1—Comparison of corroding potentials and hydrogen evolution for uncoupled specimens of steel base plate in the dry hydrogen annealed and wet hydrogen annealed conditions. Graph is for Steel X and prune juice with 13 ppm Sn (as added stannous chloride) at 140 F (60 C).

Figure 3—Effect of dissolved tin (as added stannous chloride) on the corroding potential of a wet hydrogen annealed steel base plate in prune juice at 140 F (60 C). Steel W was used in tests.

Figure 2—Comparison of hydrogen actually evolved with the theoretical based on the steel weight loss for uncoupled specimens of steel base plate in prune juice at 140 F (60 C). Tests were run on dry hydrogen annealed steel Z.
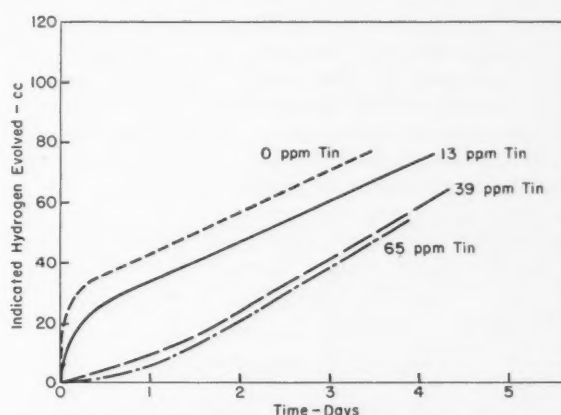
Figure 4—Effect of dissolved tin (as added stannous chloride) on the hydrogen evolved by a wet hydrogen annealed steel base plate in prune juice at 140 F (60 C). Steel W was used in tests.

and 100 F (37.8 C). No detectible hydrogen was evolved. The specimens lost weight at a constant rate throughout the test. At 140 F (60 C) the rate of tin loss was the equivalent of 1.0 cc hydrogen at STP per day; at 100 F (37.8 C), the rate of tin weight loss was the equivalent of 0.22 cc hydrogen at STP per day. Inasmuch as no oxygen was present and since no hydrogen was evolved, it was evident that prune juice must contain some depolarizer, the reduction of which allows an equivalent amount of tin to be oxidized and taken into solution. The rates of tin solution mentioned correspond to approximately 7.0 pounds per base box per year (0.420 mils per year) at 140 F (60 C) and 1.5 pounds per base box per year (0.090 mils per year) at 100 F (37.8 C). (One pound per base box corresponds to a thickness of 60 millionths of an inch of tin.)

No temperatures other than 140 F (60 C) and 100 F (37.8 C) were investigated, but for these two temperatures, the rate of tin weight loss obeyed the simple rule that the rate of reaction is doubled for every

10 degrees C rise in temperature. Using this relationship, it could be estimated that the rate of tin weight loss at 70 F (21.1 C) would be approximately 0.5 pound per base box per year (0.030 mils per year).

Data for the rate of corrosion of uncoupled tin in peaches were not determined. From the results of tests on tin plate, it was learned that the rate of detinning is about 7½ times as fast in prune juice as in peaches, indicating the existence of a more effective depolarizer in the prune juice.

It was beyond the scope of the present work to investigate intensively the detinning rates or corrosion rates of uncoupled specimens of tin. Consequently the data presented are not represented as being anything more than the corrosion rates of the particular tin specimens used in this work in the particular test media used. The aim here has been to call attention to the following facts:

1. Hydrogen is not evolved in the corrosion of uncoupled tin.
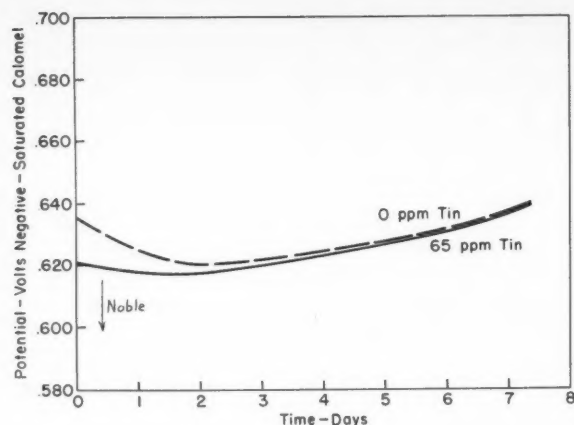
Figure 5—Effect of dissolved tin (as added stannous chloride) on the corroding potential of a dry hydrogen annealed steel base plate in prune juice at 140 F (60 C). Steel W was used in tests.

Figure 6—Effect of dissolved tin (as added stannous chloride) on the hydrogen evolved by a dry hydrogen annealed steel base plate in prune juice at 140 F (60 C). Steel W was used in tests.

2. Uncoupled tin is attacked at a constant rate which is a function of the temperature and the effectiveness of the depolarizers present in the medium.

There does not appear to be general agreement as yet on the importance of factors inherent in the tin on detinning rate. Some people believe that "tin is tin" and that detinning rates are little affected by such factors as normal variations in chemical composition, grain size, surface films, etc. Others are not so sure and believe that such factors may be of importance.

Corrosion of Base Plate

The rate of corrosion of uncoupled steel base plate in itself probably is not too important. In any event, a can will not last very long when it is completely detinned. The properties of the uncoupled base plate are principally important to the extent that they are carried over to influence the characteristics of partially detinned tin plate or a tin-steel couple.

As in the case of uncoupled black plate (uncoated steel sheet) in citric acid solution,[9] a steel base plate in prune juice which has a pickle lag corrodes more rapidly than one without a pickle lag. Corrosion rates and corroding potentials for wet and dry hydrogen annealed steel X in prune juice at 140 F (60 C) given in Figure 1 are typical. The corroding potential of uncoupled tin also is given. It is to be noted that there is a pronounced upsweep in the potential for the wet hydrogen annealed steel; for some steels these potentials actually are anodic to the tin potential. The difference between the hydrogen evolution rates of wet and dry hydrogen annealed steels in liquidized peaches is generally not quite so marked.

In the corrosion of steel black plate in prune juice at 140 F (60 C), hydrogen was evolved at the theoretical rate. This is illustrated in Figure 2. The theoretical curve was calculated on the basis of the hydrogen equivalent of the steel weight loss. These results are in direct contrast to what has been observed for uncoupled tin. With uncoupled tin, there was reduction of depolarizers with no hydrogen
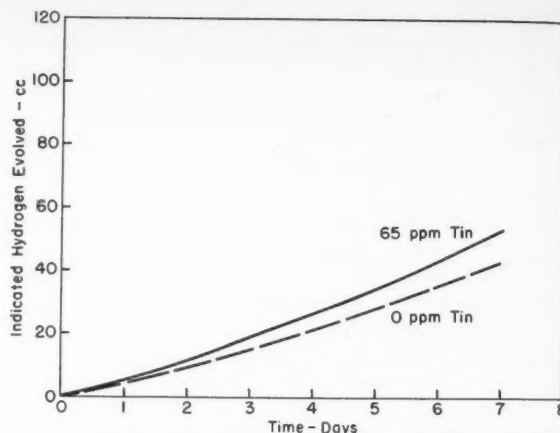
evolution; with uncoupled steel, there was evolution of hydrogen with no reduction of depolarizers. Corrosion rates of uncoupled black plate in liquidized peaches generally were found to be somewhat higher than in the prune juice, especially for the dry hydrogen annealed steels.

Dissolved tin has been shown to have a definite inhibiting effect in citric acid solution. Opinion has been expressed that the inhibiting effect of tin is as important as the polarity of the tin-steel couple. In prune juice it was actually found that the effect of the dissolved tin is quite complicated. Figures 3 and 4 show the effects of added stannous chloride on the corroding potential and the rate of hydrogen evolution of uncoupled wet hydrogen annealed steel W in prune juice at 140 F (60 C). Addition of successively larger amounts of stannous chloride to the prune juice regularly shifted the potential of the wet hydrogen annealed steel in the positive direction in agreement with the behavior observed in citric acid solution.

It can readily be seen from Figure 3 that for this steel the presence of dissolved tin is also of importance in helping establish tin as the anodic member of a tin-steel couple. Figure 4 shows that tin also exerts a definite inhibiting effect, but only at the beginning of the test. The meaning of this in terms of can corrosion is not entirely clear, but it appears reasonable to say that on the combined basis of the potential shift and the hydrogen evolution rate that dissolved tin is instrumental in increasing pack life for a wet hydrogen annealed steel.

For a dry hydrogen annealed steel in prune juice, dissolved tin had little significant effect. The effect was somewhat variable for different steels, but commonly it had a slight accelerating effect. This is illustrated in Figures 5 and 6 for uncoupled dry hydrogen annealed steel W. Tests also were run here for the 13 ppm and 39 ppm tin additions, but the data are not plotted because all the results were so close together. These results are for single potential cells. In another test with multiplicate volume type cells it was found that an addition of 65 ppm tin
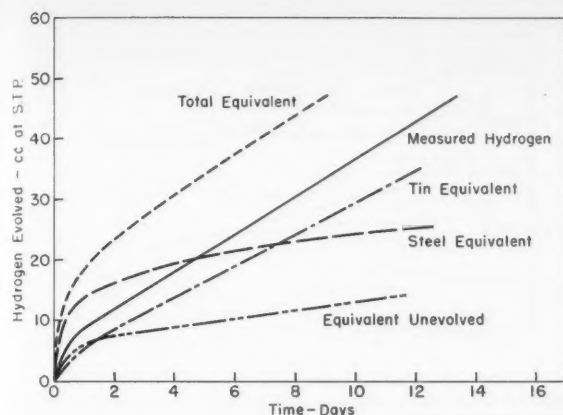
Figure 7—Hydrogen evolution and weight loss data for a wet hydrogen annealed steel base plate coupled to tin in prune juice at 140 F (60 C). Steel W was used in tests.

Figure 8—Hydrogen evolution and weight loss data for a dry hydrogen annealed steel base plate coupled to tin in prune juice at 140 F (60 C). Steel W was used in tests.

TABLE 2—Numerical Ratings for the Results of Tests on Tin-Steel Couples in Prune Juice at 140F (60C)

STEEL	Annealing Atmosphere	Time for Evolution of 10 cc H₂ at STP—Days	Hydrogen Evolved in 7 Days cc at STP	Final Rate of H₂ Evolution— cc per Day
W	Dry H₂	21.8	3.5	0.44
	Wet H₂	1.5	27.4	3.2
X	Dry H₂	12.4	6.5	0.66
	Wet H₂	2.9	16.3	1.5
Y	Dry H₂	17.4	4.0	0.5
	Wet H₂	0.8	57.9	3.6
Z	Dry H₂	3.9	13.3	0.9
	Wet H₂	1.3	28.0	2.7

increased the corrosion rate of dry hydrogen annealed steel W by approximately 80 percent.

From these data it would appear reasonable to conclude that in actual fruit products, dissolved tin may be instrumental in prolonging the shelf life in some cases; however, there will be found cases in which it provides no benefit. An inhibiting effect of dissolved tin cannot be predicted without adequately investigating the case in question.

The Tin-Steel Couple in Prune Juice

In prune juice at 140 F (60 C) there was a much greater difference in hydrogen evolution rate between the dry and wet hydrogen annealed conditions when the steel was coupled to tin. This is illustrated for wet and dry hydrogen annealed steel W in Figures 7 and 8. These tests were run using a series of tin-steel couples in from 7 to 10 test cells all started at the same time. In all couple tests, unless otherwise noted, an addition of 13 ppm Sn⁺⁺ (as SnCl₂) was added to the corrosive medium.

Hydrogen evolved was measured for each cell throughout the test. One test cell was discontinued each day to determine the weight loss of the tin and the steel in that time. Reproducibility in these tests was always excellent, and the curves shown very closely approximate the experimental points, which are omitted principally to make the figures clearer. The "total equivalent" curve shown represents the
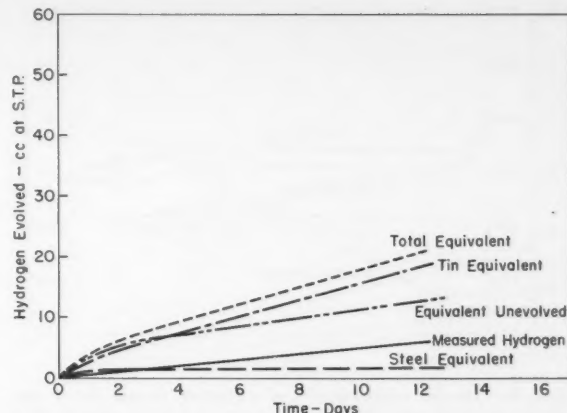
sum of the hydrogen equivalent of the tin dissolved and the hydrogen equivalent of the steel dissolved. The "equivalent unevolved" is the difference between the total equivalent and the actual evolved hydrogen. After approximately the first day, it represents the rate of reduction of depolarizers present.

For the four steels tested there were certain variations in the results, but the folowing points were evident:

1. There was a great difference in hydrogen evolved between wet and dry hydrogen annealed steels. This difference was much greater than was found in citric acid solution or the difference which was indicated in tests on uncoupled black plate in prune juice. In connection with such results, various quantities could be used as an index of the corrosion rate of a particular tin-steel couple. Table 2 shows the results for the four steels tested in both the wet and dry hydrogen annealed conditions as rated by three separate systems. The wide differences are evident no matter which rating system is used. Considerable variations are shown for the different steels, but there was always a great difference between the results for the wet and the dry hydrogen annealed conditions.

2. The wet hydrogen annealed steels were attacked much more rapidly than the dry. Except for a small amount of attack occuring at the beginning of the test, the dry hydrogen annealed steels were completely protected by the tin. The wet hydrogen annealed steels were not.

3. The rate of reduction of depolarizers was roughly constant. Evidently this occurred only on the surface of the tin and was not dependent on the material to which the tin was coupled.

4. The rate of solution of tin was markedly increased by coupling to steel. Rates of tin
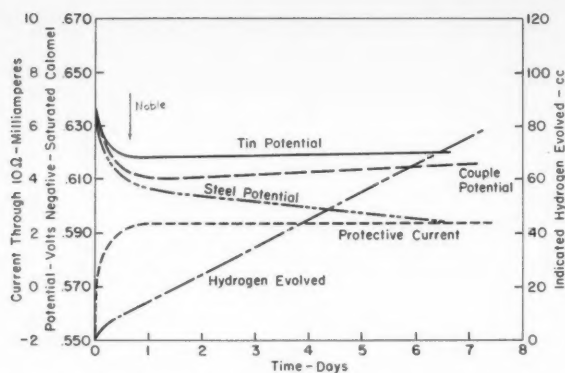
Figure 9—Potential relationships and protective current for a wet hydrogen annealed steel base plate coupled to tin in prune juice at 140 F (60 C). Steel W was used in tests.
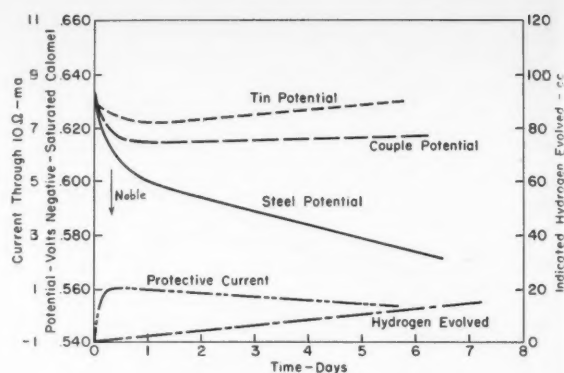
Figure 10—Potential relationships and protective current for a dry hydrogen annealed steel base plate coupled to tin in prune juice at 140 F (60 C). Steel W was used in tests.

TABLE 3—Corrosion Rates of Tin in Prune Juice

	RATE OF CORROSION (mils per year)	
COUPLED TO	At 140 F (60 C)	At 100 F (37.8 C)
Nothing	0.42	0.09
Dry W	0.55	0.13
Wet W	1.3	0.21
Dry X	0.59	0.17
Wet X	0.76	0.25
Dry Y	0.55	0.13
Wet Y	1.4	0.21
Dry Z	0.76	0.25
Wet Z	1.1	0.34

TABLE 4—Results of Vacuum Fusion Analysis for Hydrogen in Steels After Corrosion Testing in Prune Juice at 140F (60C), Coupled to Tin

STEEL	Hydrogen Annealing Atmosphere	Days Tested in Prune Juice	Hydrogen— Percent
X	Dry	0	0.00015
		1	0.00015
		7	0.00020
		14	0.00025
X	Wet	0	0.00010
		1	0.00070
		7	0.00070
		14	0.00165
Z	Dry	0	0.00010
		1	0.00010
		7	0.00005
Z	Wet	0	0.00010
		1	0.00050
		7	0.00180

solution were greater when coupled to wet hydrogen annealed steels than when coupled to the dry. Comparisons for all the steels tested at both the 140 F (60 C) and the 100 F (37.8 C) testing temperatures are shown in Table 3. Inasmuch as the rate of tin solution as well as the rate of steel solution was increased with the wet hydrogen annealed steel, it is indicated that a cathodic property of the steel is involved.

It might also be mentioned that corrosion rates of tin-steel couples in prune juice were considerably lower than in citric acid solution or in citric acid-sodium citrate solutions of the same pH (3.75) as prune juice. This indicates the effect of inhibitors in the food product.

The effect of stannous chloride additions in tests on tin-steel couples in prune juice at 140 F (60 C) also was investigated. It was found that the effects noted in the comparable tests on uncoupled black plate were carried over into the tests on tin-steel couples.

Potential Relationships in Prune Juice at 140 F (60 C)

Potential relationships for coupled wet and dry hydrogen annealed steel W in prune juice at 140 F (60 C) are shown in Figures 9 and 10. All potentials are relative to the saturated calomel electrode. The tin and steel potentials were taken by uncoupling and measuring after one minute. Reasons for this procedure have been explained in an earlier paper.[9] The magnitude of the protective current was deter-

mined by coupling the tin and the steel through a 10 ohm resistance and measuring the potential drop across the resistance. In some of the work, a zero resistance ammeter was used.

From these data, as well as those for the other steels tested, the following points were noted:

1. The protective current, or the galvanic current between the tin and the steel, was found to be higher for the wet hydrogen annealed steels than for the dry. Again this indicates that the difference between the wet and the dry hydrogen annealed steels in prune juice is largely cathodic in nature.

2. As would be expected from the pronounced cathodic influences, there was no simple relationship between corrosion rate and corroding potential, although lower corrosion rates are to be associated with steel potentials which shift markedly in the cathodic direction.

By putting various size resistors between the steel and the tin, polarization curves were investigated. It was found that the dry hydrogen annealed steel polarized as a cathode far more readily than the wet.

Hydrogen dissolved by the steel in the course of a coupled test in prune juice at 140 F (60 C) was
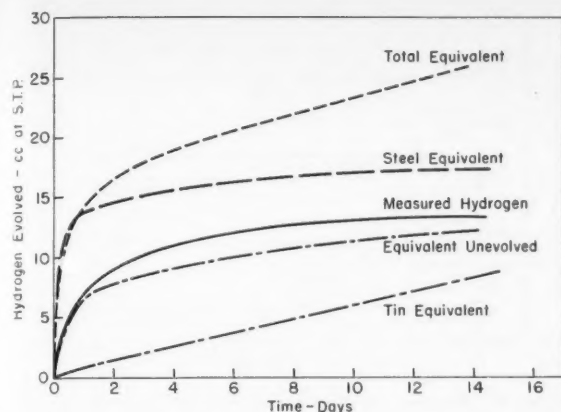
Figure 11—Hydrogen evolution and weight loss data for a wet hydrogen annealed steel base plate coupled to tin in prune juice at 100 F (37.8 C). Steel Y was used in tests.

Figure 12—Hydrogen evolution and weight loss data for a dry hydrogen annealed steel base plate coupled to tin in prune juice at 100 F (37.8 C). Steel Y was used in tests.

determined for some of the steels tested. Vacuum fusion analyses were made on the steels within 20 minutes after discontinuing the corrosion test. Results are given in Table 4. It is seen that there was a considerable amount of hydrogen dissolved for the wet hydrogen annealed steels while the dry hydrogen annealed steels dissolved essentially no hydrogen. It would appear from the fact that the wet hydrogen annealed steels both dissolved and evolved more hydrogen, that more hydrogen actually reached the surface of the wet hydrogen annealed steels and was adsorbed. This suggests the existence in prune juice of an inhibitor which for some reason is more readily adsorbed on the surface of a dry hydrogen annealed steel than a wet one.

Relationships of Coupled Tests to Uncoupled Tests

It has been claimed[10] that the results of tests on uncoupled black plate may be used to indicate the merit of the base plate. It has been mentioned that the properties of uncoupled black plate are of importance principally to the extent that such properties are carried over to the tin-steel couple. The value of a test on uncoupled steel black plate in rating corrosion performance must be based on a consistent relationship between hydrogen evolution rates for the tin-steel couple and for black plate.

It was found that there was a much greater difference between the dry and wet hydrogen annealed steels in coupled tests than in uncoupled tests. As a result of this, the relationship between test results for black plate and for tin-steel couples was found to be considerably different depending on whether the steel did or did not possess a pickle lag. Since the degree of pickle lag in commercial tin plate is subject to variation, no consistent relationship between tests on black plate and tests on tin-steel couples (or pack tests) is to be anticipated. The uncoupled corrosion rate could be expected to serve only as a rough qualitative estimate which could be far off for particularly bad steels.

Anodic Coupling Shift

Normally the concept of cathodic protection re-

quires an increase in the rate of the reduction processes occurring at the cathodes. This would mean an increase in the rate of hydrogen evolution for a coupled piece of steel over its hydrogen evolution rate when uncoupled. Actually, however, it was found that there was a very large decrease in the hydrogen evolution rate on coupling. This had been previously noted and had been explained on the basis of the inhibiting effects of dissolved tin.
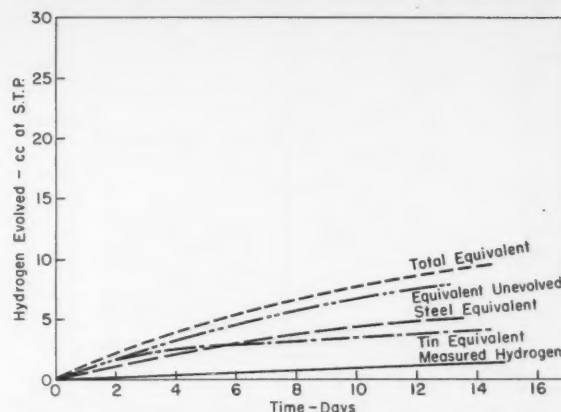
It may be remembered from the above information that the greatest decrease in the rate of hydrogen evolution on coupling was for the dry hydrogen annealed steels; yet, dissolved tin here showed no inhibiting effect in prune juice. This explanation, therefore, certainly can not be valid although in some cases it will exert a contributing effect.

The decrease in hydrogen evolution rate is explainable on the basis of the anodic coupling shift which has been noted previously in citric acid.[9] This involves a shift in the anodic polarization curve for the steel which in some unexplained manner occurs on coupling to the tin. It is seen in Figures 9 and 10 that the anodic coupling shift, as evidenced by the displacement of the steel potential in the cathodic (positive, noble) direction, was considerably greater for the dry hydrogen annealed steels in prune juice than for the wet. Since the success of the plain can is dependent largely upon the decrease in hydrogen evolution as well as the protection of the steel, it is largely traceable to this phenomenon of the tin-steel couple.

Tests at 100 F (37.8 C)

The 140 F (60 C) test temperature was used to get test results as rapidly as possible. This was particularly desirable when comparative tests were to be made on tin plate, for tests on tin plate involve a relatively long detinning period at lower temperatures before the test yields the desired information. Another advantage of the 140 F (60 C) test temperature was that there was no problem of food spoilage. It was, of course, realized that the 140 F (60 C) test temperature is higher than that to which cans are subjected in storage.
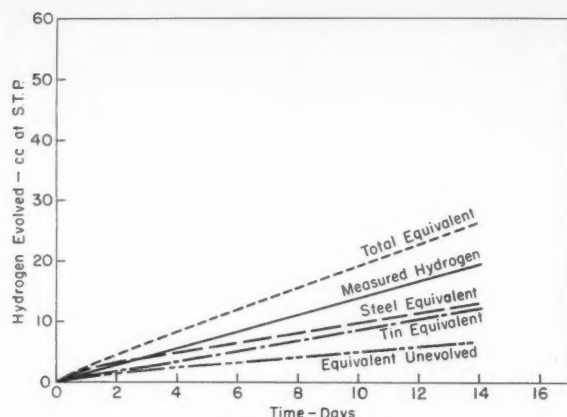
Figure 13—Hydrogen evolution and weight loss data for a dry hydrogen annealed steel base plate coupled to tin in liquidized peaches at 140 F (60 C). Steel X was used in tests.
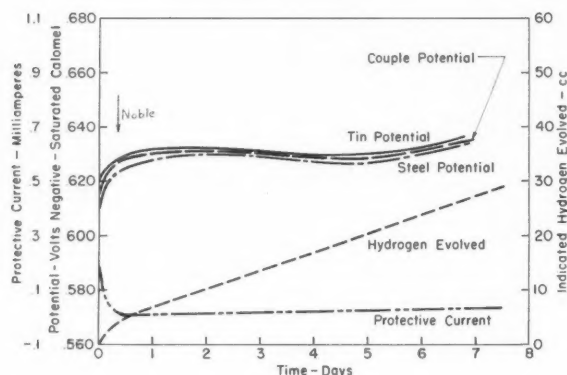
Figure 14—Potential relationships and protective current for a wet hydrogen annealed steel base plate coupled to tin in liquidized peaches at 140 F (60 C). Steel W was used in tests.

To meet possible objections, tests also were run in prune juice at 100 F (37.8 C) which is an accepted standard test temperature in the can industry. Typical results for a wet and a dry hydrogen annealed steel, steel Y, coupled to tin in prune juice at 100 F are shown in Figures 11 and 12. The following points may be noted:

1. Again, a very wide difference between the wet and the dry hydrogen annealed steels was shown.

2. Tin dissolved more slowly and appeared to afford less protection at 100 F (37.8 C).

3. The dry hydrogen annealed steel was attacked very slowly, but it was not quite fully protected.

4. There was less effective protection of the steel than at 140 F (60 C).

5. 100 F (37.8 C) tests differentiated between wet hydrogen annealed steel and dry hydrogen annealed steel to about the same extent as the 140 F tests. There was found to be a greater spread between the results for the dry hydrogen annealed steels at 100 F (37.8 C) than at 140 F (60 C).
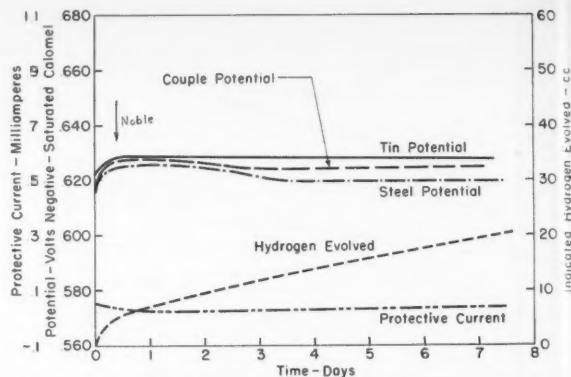
Figure 15—Potential relationships and protective current for a dry hydrogen annealed steel base plate coupled to tin in liquidized peaches at 140 F (60 C). Steel W was used in tests.

TABLE 5—Hydrogen Volume and Weight Loss Results for Dry and Wet Hydrogen Annealed Steels Coupled to Tin in Liquidized Peaches at 140F (60C)

Steel	Time of Test-Days	Hydrogen Equivalent of Steel Weight Loss cc at STP	Hydrogen Equivalent of Tin Weight Loss cc at STP	Hydrogen Equivalent of Total Metal Oxidized cc at STP	Measured Hydrogen Evolved cc at STP	"Unevolved" Hydrogen cc at STP
Dry W	7	10.7	3.8	14.5	11.8	2.7
Wet W	7	16.1	3.9	20.0	16.2	3.8
Dry X	7	6.2	4.3	10.5	6.5	4.0
Wet X	7	6.4	4.6	11.0	8.7	2.3
Dry Y	8	6.3	7.6	13.9	8.1	5.8
Wet Y	8	11.5	6.2	16.7	13.0	3.7
Dry Z	3	7.3	1.7	9.0	6.6	2.4
Wet Z	3	9.5	1.6	11.1	8.0	3.1

It would appear that if coupled tests alone are desired, there is very little advantage in making tests at 140 F (60 C) over the 100 F (37.8 C) except that foods other than prune juice might spoil. Tests on tin plate at 140 F (60 C) are considerably faster and if it is desired to compare coupled test results with results on actual tin plate, this test temperature is advantageous. While there are certain differences between the test results at 140 F (60 C) and 100 F (37.8 C), the coupled tests made at the higher temperature serve, in general, to give the same desired information in prune juice.

Peaches

Not as much work was done in the peaches as in the prune juice, but it could be determined that the two food products had vastly different behavior. Volume cell results for dry hydrogen annealed steel X in liquidized peaches are given in Figure 13. The data for wet hydrogen annealed steel X were found to be practically identical and so are not given.

Data for all of the steels are summarized in Table 5. Unfortunately, data for steel Z are available only for a three day test period. It is to be noted that differences between the dry and wet hydrogen annealed conditions appeared, but that they were very small compared to what was found in prune juice. What difference exists appears to be anodic in nature inasmuch as the differences in hydrogen evolution seem accountable entirely in terms of steel weight loss, there being no difference in the tin
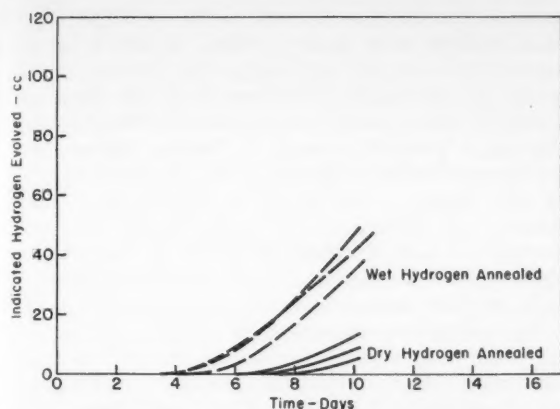
Figure 16—Comparison of hydrogen evolved for tin plated specimens of dry hydrogen annealed and wet annealed base plate in prune juice at 140 F (60 C). Steel Y, tin plated to 0.37 pound per base box from alkaline bath, was used in tests. Tin was not flow brightened.

TABLE 6—Effects of Coupling to Tin on Hydrogen Evolution and Weight Loss Results in Liquidized Peaches—7 Days at 140F (60C) for a Mill Annealed Black Plate

	HYDROGEN EQUIVALENT—cc at STP		
	Uncoupled	Coupled, 1 Anode	Coupled, 2 Anodes
Steel Equivalent......	23.2	10.7	2.1
Tin Equivalent......	......	4.5	7.3
Total Equivalent......	23.2	15.2	9.4
Measured Hydrogen...	19.8	11.5	6.0
Equivalent Unevolved.	3.4	3.7	3.4

weight loss. In these respects, peaches are similar to citric acid solution rather than to prune juice.

These indications are confirmed by potential cell data, typical examples for which are given in Figures 14 and 15. It is seen that there was a somewhat greater rate of hydrogen evolution for the wet hydrogen annealed steel than for the dry. The protective currents were found to be identical and to be quite low. As in the case of citric acid solution, more negative potentials were registered for the more rapidly corroding steel.

In peaches the tin was not able to protect the steel at as great a distance as in prune juice. This is traceable to the small difference between the uncoupled potentials of the steel and tin as noted in Figures 14 and 15 and to some degree to the relatively low electrolytic conductance of the liquidized peaches. The specific conductance of peaches was about one-third that of the prune juice.

It will be recalled that the test couple used consists of one piece of tin and one piece of black plate. Because of the fact that the protective effect of the tin does not extend to as great a distance in the peaches, it was found by visual examination that the side of the black plate facing the tin appeared well protected, while the reverse side appeared poorly protected. In view of the magnitude of the protective currents indicated in Figures 14 and 15, it might appear surprising that there was any significant protection. To check the extent of protection by such a small current, a comparative test was run on a mill
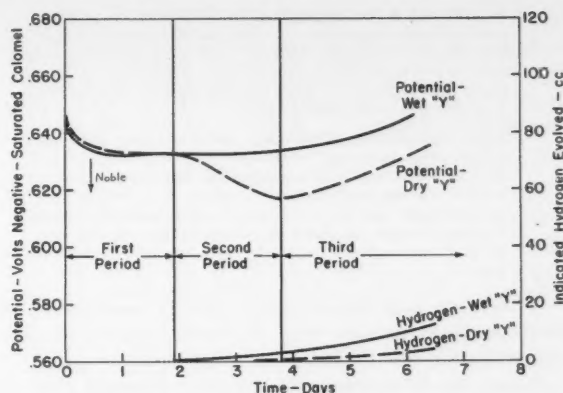
Figure 17—Comparison of corroding potentials and hydrogen evolved for tin plated specimens of wet and dry hydrogen annealed steel base plate. Steel Y was used in tests and tin was not flow-brightened.

annealed black plate with five test cells for each of the following conditions:

1. Uncoupled steels.

2. Coupled to one tin anode.

3. Coupled to two tin anodes, one on each side of the steel sheet.

The test was run for seven days. Reproducibility for the cells in any group was excellent. Results are given in Table 6. Coupling to two anodes produced a marked reduction in iron solution. Between the one and two anode conditions it is seen that an increase in the tin solution rate to the extent of 2.8 cc H₂ equivalent reduced the rate of attack on the steel by 8.6 cc H₂ equivalent. It is again evident that the anodic coupling shift mechanism must be operating.

Tests on Tin Plate

A test on tin plate parallels an actual pack test and represents a composite of the corrosion of uncoupled tin, the corrosion of the tin-steel couple and the corrosion of the uncoupled steel. The corrosion of tin plate here may be divided into three periods:

1. **Steel Essentially Completely Covered by Tin.** In this period tin goes into solution concurrently with the reduction of depolarizers present in the product. Any steel base exposed at the pores is sacrificially protected, but the total area of steel base exposed at the pores is too small to influence the corrosion picture and no significant amount of hydrogen is evolved. It would be expected that corrosion in this period is essentially the corrosion of uncoupled tin and that the corrosion rate of the tin is unaffected by the characteristics of the base plate. At the present time there seems to be rather general agreement that for the type of corrosion under consideration the effect of porosity is of no importance, but in spite of this there is not general agreement that the characteristics of the base plate do not affect the corrosion rate of the tin. Vaurio[10] found in his tests that the rate of solution of the tin coating at 100 F (37.8 C) is not dependent on the corrosion resistant qualities of the steel base, but not everyone appears convinced.

2. **Significant Area of Steel Base Exposed.** Corrosion mechanisms operative in this period are those of the tin-steel couple and in this period the steel base exerts its influence on the pack life. A can may fail before the end of this period and never actually get into period three.

3. **Can Completely Detinned.** While there will be differences between the steels, in any event this period would not be expected to last more than a matter of weeks for prune juice. It must be assumed that the life of a can is largely determined by the length of time it takes to get up to this period and not so much by what goes on in this period.

There are indications that in many food products the corrosion picture may be somewhat more complicated than the above.

Tests to determine the actual vacuum loss in packed cans as well as other data are in agreement with results of this work that no hydrogen is evolved in the first period. It is a little hard to define the precise end of the first period. It seems to be a gradual transition. The time hydrogen starts to be evolved as well as the rate of hydrogen evolution are both functions of the steel base. This is shown in Figure 16 where hydrogen evolution results for three cells with tin plated wet hydrogen annealed steel Y and three cells with plated dry hydrogen annealed steel Y are given. The coating thickness in this case was 0.37 pound per base box and the plate was not flow-brightened.

The interpretation to be given seems to be that the wet hydrogen annealed steel starts to evolve hydrogen as soon as a small amount of steel is exposed, while the dry hydrogen annealed steel evolves hydrogen but slowly as long as some tin remains on the surface to protect it. This viewpoint is supported by potential cell results for plated wet and dry hydrogen annealed steel Y as in Figure 17. The potential of the wet hydrogen annealed steel was rather insensitive to the relative amounts of tin and steel exposed, but that of the dry hydrogen annealed steel showed a sharp dip as soon as steel started to be exposed. Hydrogen evolution commenced at this time for the wet hydrogen annealed steel but not for the dry hydrogen annealed steel. When completely detinned, the potential of the dry hydrogen annealed steel again became more anodic; hydrogen evolution for the dry hydrogen annealed steel started shortly before this.

It was found, in general, that the indications of the tin-steel couple tests carried over to differences in tests on tin plate. The tin plates representative of the steels considered here were not tested in the flow-brightened condition. This was not considered necessary as it has already been established that pickle lag survives the flow brightening operation to exhibit its influences in packed cans.[1] The aim here has been to learn something of the mechanisms involved. In connection with other work, a considerable amount of flow-brightened tin plate was tested in the manner used here, and no reason was found to alter the above concepts.

Summary

It has been the aim here to consider in some degree the correlation of influences existing in the tin plate and in the can contents on the shelf life of plain cans packed with fruit products. It has long been known that certain influences present in the base plate are of considerable importance for some food products and of little or no importance for others. In the past, pack data have indicated almost every product to behave differently. It is believed that this is the result of variations in degree of a limited number of factors, rather than a series of specific factors for each product. No claim is made that all such factors are understood or recognized here, but it is possible to call attention to some of them.

In the life of a tin can packed with a product such as prune juice, the first period is one in which simple detinning occurs, presumably with no influence of the steel base. The following factors determine the length of this period:

1. Thickness of the tin coating (and uniformity of thickness).

2. Effectiveness of depolarizers present in the food product.

3. Possible influences of natural inhibitors in the product on the rate of solution of tin.

4. Possibly factors inherent in the tin coating.

Accepting the findings of Vaurio that the detinning rate is not affected by the corrosion resistant properties of the base plate in this period, any increase in the length of the first period is directly reflected in increase in shelf life regardless of the base plate. This, then, is a function of:

1. The detinning rate.

2. The coating thickness.

For the two products tested, prune juice detinned much faster than peaches and the shelf life of prune juice in cans would be expected to be the shorter for this reason alone—as it normally is—regardless of the corrosion resistance of the base plate.

A second period of corrosion commences as soon as a significant area of steel base is exposed. The properties of the steel base are quite important in this period and the situation is quite complicated. The following are suggested as possible factors, variable from steel to steel and from food product to food product, which determine corrosion resistance in this period.

1. Anodic properties of the steel base.

2. Inhibitors present in the product.

3. Properties of the steel or steel surface which influence its power to adsorb certain of these inhibitors.

4. Known and unknown factors which influence the potential relationships between steel and tin. This includes the unexplained "anodic coupling shift."

It is to be noted that the effect of pickle lag is variable with respect to the product and that the effect of dissolved tin as an inhibitor is related to both the corroding medium and to pickle lag. It is

further to be noted that in prune juice more hydrogen is adsorbed on the surface of a steel with a pickle lag than on a steel without the pickle lag. This suggests that the effect of pickle lag with prune juice is through inhibitors present in the product which adsorb more readily on the dry hydrogen annealed steel than on the wet hydrogen annealed steel.

Acknowledgments

References

1. A. R. Willey, J. L. Krickl and R. R. Hartwell. Steel Surface Properties Affect Internal Corrosion Performance of Tin Plate. *Corrosion,* **12,** No. 9, 433t (1956) Sept.
2. E. L. Koehler. The Rate of Pickling Test for Tin Plate Steels and Its Metallurgical Significance. *Transactions, American Society for Metals,* **44,** 1076 (1952).
3. W. E. Hoare. Assessing the Corrosion Behavior of Tin-plate. *Sheet Metal Industries,* 234 (1955) Mar.
4. T. P. Hoar. The Electrochemical Behavior of the Tin-Iron Couple in Dilute Acid Media. *Technical Publications,* International Tin Research and Development Council, No. 5, Series A.
5. R. H. Lueck and H. T. Blair. Corrosion in Tin Cans. (Electrochemical Relations of Tin and Iron). *Transactions Electrochemical Society,* **54,** 257 (1928).
6. E. F. Kohman and N. H. Sanborn. Factors Affecting the Relative Potentials of Tin and Iron. *Industrial and Engineering Chemistry,* **20,** 1373 (1928).
7. R. R. Hartwell. Corrosion Resistance of Tin Plate—Influence of Steel Base Composition on Service Life of Tin Plate Containers. *Surface Treatment of Metals,* American Society for Metals, 1941.
8. T. P. Hoar and D. Havenhand. Factors Influencing the Rate of Attack of Mild Steel by Typical Weak Acid Media. *Technical Publications,* International Tin Research and Development Council, No. 36, Series A.
9. E. L. Koehler. The Tin-Steel Couple in Air-Free Citric Acid Solution. *Journal of the Electrochemical Society,* **103,** No. 9, 486 (1956) Sept.
10. V. W. Vaurio. Some Aspects of the Corrosion of Tin Plate by Prunes. *Corrosion,* **6,** 260 (1950).

Any discussions of this article not published above will appear in the June, 1957 Issue.

Corrosion Measurements in a

Hydrogen Sulfide-Water Absorption Pilot Plant*

By B. W. BRADLEY and N. R. DUNNE

Introduction

IN APRIL of 1951 Shell Oil Company discovered a gas reservoir which contained an exceptionally large percentage of hydrogen sulfide. By mid-1954 sufficient reserves had been proven to warrant preparation of plans for construction of central gas processing facilities. Almost half of the gas in this field consisted of acid gases (see Table 1). Therefore, production and marketing considerations included sulfur manufacturing and the sale of sweetened gas.

In view of the large percentage of acid gas to be removed (ca. 45 percent), it was obvious that a conventional sweetening plant, employing a water solution of monoethanolamine, would involve a high utility operating cost. For this reason consideration was given to the use of a water absorption plant. Preliminary calculations indicated that because of the water solubilities and high partial pressures of the acid gases, significant quantities of acid gas could be extracted by a process of high pressure absorption followed by low pressure desorption. Very little, if any, heating or cooling requirements were indicated.

These estimates were based on literature data concerning the solubility of hydrogen sulfide in water. Therefore it was essential to establish the reliability of the available equilibrium ratios. This could best be done on a bench scale or pilot plant basis. A pilot plant was selected as the test method since it also would provide needed experience with producing the wells. Although the primary purpose of the pilot plant was to establish absorption characteristics, extensive corrosion tests were planned for the test period. The purpose of this report is to summarize the corrosion measurements obtained during the operation of the pilot plant.

Description of the Plant

The flow diagram of the pilot water absorption plant which is shown schematically in Figure 1 consisted of a high pressure absorber column and a low pressure degasifying drum, a water circulation pump, filter, heat exchanger, and gas scrubbers.

All vessels were constructed of carbon steel and stress relieved. Carbon steel piping was fabricated on location but not stress relieved. Stainless steel Type 304 thermometer wells were used throughout the plant. Although Monel or aluminized relief valve springs were specified, they were unavailable and ordinary spring steel was used in the test.

To facilitate corrosion measurements removable coupon holders were located at nine locations as

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Abstract

In evaluating gas processing facilities to sweeten an extremely sour natural gas, technologists estimated high pressure water absorption followed by simple low pressure flashing would be attractive. Consideration of reduced heat exchange and stripping heat requirements indicated that appreciable savings in investment and operating cost could be effected by the process. Accordingly, a water absorption pilot plant was constructed and operated for a brief period to establish the absorption and desorption characteristics under the existing field conditions. Since corrosion problems were anticipated, a series of corrosion evaluation tests were conducted concurrently in the pilot plant.

Carbon steel corrosion rates, although very high during the first few hours or days, were found to diminish to a tolerable level within the 19-day test. Killed carbon steel, stainless steel Type 304, Inconel and K-Monel, were found resistant to sulfide stress corrosion cracking. Inconel, Monel, and 304 also showed low weight loss corrosion. Hydrogen probes indicated decreasing corrosion rates in absorber and degasifying drums during the test period. A water dispersable, amine type inhibitor reduced carbon steel corrosion rates and indicated protection from sulfide stress corrosion cracking.

Data indicated stress relieved carbon steel vessels and piping with corrosion resistant alloys for critical process parts, such as pumps, Bourdon tubes, thermometer wells, orifice plates, and relief valve springs would provide acceptable service life. The test data also indicate carbon steel weight loss and sulfide corrosion cracking severity of the environment can be reduced by inhibition. **8.4.3**

shown in Figure 1. In addition, racks of alloy and cracking coupons were mounted in the top and bottom Raschig ring beds. A hydrogen probe was mounted in both the absorber and degasifier as shown.

Plant Operation

The plant operated intermittently for periods of several hours to several days during a seven-week period. Most shutdowns were of short duration for mechanical changes or repairs. Except while changing the column internals from Raschig rings to bubble caps, an oxygen-free environment was held in the plant.

From a corrosion standpoint the time considered as representative of operating environment included a total of 19 days at normal plant pressure with water circulation and gas flow. Although the gas and water rates were varied throughout the test to obtain a wide range of absorption data, it was felt the environment approximated that of a commercial plant. The absorber operated at several pressure levels between 500 and 700 psig; the degasifier operated at 6 and 15 psig.

Carbon Steel Corrosion

As previously mentioned and as shown in Figure 1, arrangements to expose carbon steel coupons were provided throughout the plant. The strip-type coupons were mounted in duplicate on removable holders. Each coupon was insulated from the holder.

A program of exposure times was selected in an effort to check the only similar but unpublished, corrosion experience known at the time of the pilot plant test. This experience, depicted by Figure 2, reported very high corrosion during the first few hours or days, which declined to a level of about 10 mils per year in a few months. For purposes of planning these tests, it was assumed that the 10 mils per year rate would occur one year after start-up. On this basis exposure times of 1, 2, 24, 48, 168, and 336 hours were to be made if possible during the limited pilot plant operation for carbon steel coupons at coupon exposure point 6 on Figure 1. It was felt this would be the point of highest acid gas partial pressure and the most acidic water. Therefore, the highest corrosion rates were expected at this point. Carbon steel coupon changes for the other exposure points were to be made as often as convenient.

Average corrosion rates measured in the bottom of the absorber (point 6, Figure 1) are shown on Figure 3. These rates were slightly lower than anticipated, but exhibited the expected trend with time. Similar measurements at other points for two exposure times also are shown in Figure 3. Except for exposure point 9, located in the degasifying drum, the corrosion rate declined with time. Abrasive action of water impinging on the coupon at point 9 might account for the difference observed at that point.

The surface condition of the coupons at the conclusion of these tests is shown in Table 2. The conditions consisted of varying degrees of corrosion, blistering, and scale. In general, the coupons with longer exposure times were prone to show numerous
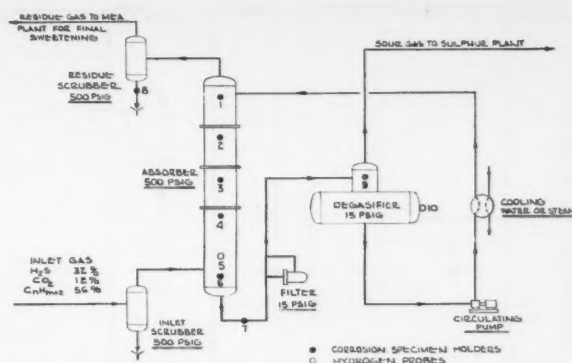
Figure 1—Schematic process diagram of hydrogen sulfide-water absorption pilot plant.

TABLE 1—Composition of Gas Feed to Hydrogen Sulfide-Water Absorption Pilot Plant

CHEMICAL	Content
Hydrogen Sulfide	35.00%
Carbon Dioxide	10.12%
Nitrogen	1.31%
Methane	52.25%
Ethane	0.69%
Propane	0.16%
Butanes	0.10%
Pentanes	0.07%
Hexane plus	0.30%

TABLE 2—Surface Condition of Carbon Steel Coupons After Exposure in Hydrogen Sulfide-Water Absorption Pilot Plant

No.	Exposure Location	Exposure Time in Hours	Average Corrosion Rate in MPY	Coupon Appearance[1]
1	Absorber Top	47 220	71 30	xx xx Ss
2	Absorber 2nd Section	47 220	102 10	oo oo
3	Absorber 3rd Section	47 220	62 22	oo oo
4	Absorber 4th Section	47 220	82 22	oo oo
6	Absorber Bottom	1 2 47 100 118	1055 620 114 42 56	oo oo xx oo SS oo SS
7	Rich Solution Line	47 220	56 15	xo oo s
8	Tail Gas Scrubber Drain[2]	1 2 26 100 139	300 263 327 15 64	oo oo XX oo s XX s
9	Flash Tank	26 242	77 54	xx XX

[1] Code to coupon appearance
  o No blistering
  x Few blisters
  X Numerous blisters
  s Some adherent scale
  S Much adherent scale

[2] Corrosion rate data inconsistent. Possibly due to location in deadleg

blisters or a coating of adherent scale. Coupons located in the middle of the column exhibited corrosion only.

Sulfide Corrosion Cracking

In view of the sulfide corrosion cracking failures experienced in extremely sour oil and gas wells during recent years, a series of cracking tests were
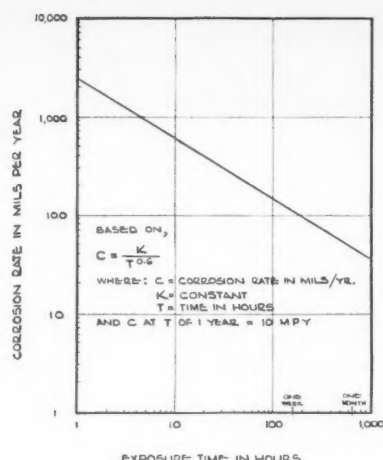
Figure 2—Anticipated corrosion rate of carbon steel in hydrogen sulfide-water absorption pilot plant.
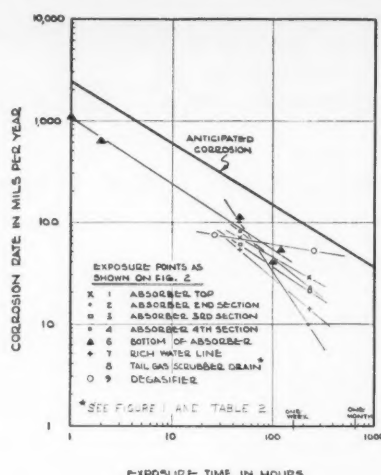
Figure 3—Carbon steel corrosion rates in hydrogen sulfide-water absorption pilot plant.

Figure 4—Assembly for use in field tests. Each specimen is held in a separate unit holder and is insulated from it by small glass rods. The specimen is insulated from the loading screw by a small glass bead. Each unit holder is separated from its neighbors by wire screen.
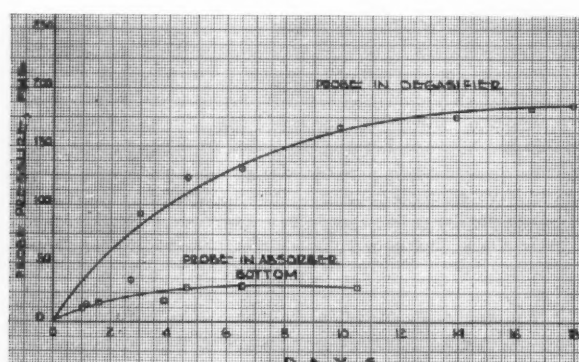
Figure 5—Pressure build-up in hydrogen probes in hydrogen sulfide-water absorption pilot plant.

TABLE 3—Sulfide Corrosion Cracking Results in Hydrogen Sulfide-Water Absorption Pilot Plant

ALLOY	Relative Cracking Susceptibility, S_c[1]	COUPON LOCATION[2]		
		Abs. Top	Abs. Btm.	Filter
9 Ni	0.6	F, F	M	
9 Ni	1.4	F, F	M	
9 Ni	2.0	S		
SAE 4340	2.1	F, F	M	
9 Ni	2.7	F	M	
5 Ni	3.3	S	S, S, S	
P 110	3.6	F	M	
12 Cr (hard)	4.0	F		
9 Cr 1 Mo	5.2	F	M, M	F[3], F[3]
N-80 normalized	6.1	F	S, M	
N-80 normalized	8.3	S	M	
N-80 warm worked	9.0	S	S	
N-80 cold drawn	9.2	S	S	
N-80	9.8	S		
12 Cr (soft)	10.4	S	S	
J-55	11.2	S	S	
N-80 (Q & T)	11.9	S	S	
Welded ASTM 285, Gr. C	> 17			S[3], S[3]
Welded ASTM 285, Gr. B	> 17	S		
ASTM 285, Gr. C	> 17			S[3], S[3]
Al 63S-T-6	> 17		S	
304	> 17		S	S[3], S[3]
K-Monel	> 17		S	— —
Inconel	> 17		S	— —

[1] Based on laboratory results using method described in Reference 1.
Code to letters is as follows:
[2] S—Survived. F—Failed. M—Missing, assumed failed.
[3] Operating time during exposure was 142 hours for these specimens.
All others were exposed for 267-operating hours during a 23-day period.

TABLE 4—Corrosion Summary of Alloy Specimens in Hydrogen Sulfide-Water Absorption Pilot Plant

ALLOY	CORROSION RATE IN MPY[1]	
	Absorber Top	Absorber Bottom
304	0.04, 0.07	<0.1, <0.1, 0.6
302	0.1, 0.07	<0.1, 0.2
Carpenter 20	0.06, 0.06	<0.1, <0.1
Ni-O-Nel	0.04, 0.04	<0.1, <0.1
316	0.05, 0.04	0.1, <0.1
Inconel	0.1, 0.1	0.2, <0.1, 1
K-Monel		1
Monel	3, 3	2, 3
Nickel	2, 2	2, 3
430	4, 0.9	2, 2
Admiralty (Sb)	3, 2	2, 2
Al 2-S	3, 3	5, 6
410	3, 4, 4, 7	5, 4, 3
Al 63S-T6		11
Ni Resist (1)	15, 15	12
9 Ni	21	
5 Ni	23	17
Mild Steel	35, 34	37, 38
N-80	30, 36	
Welded Gr. B	38	
Cast Iron	68	50

[1] Specimens in column 23 days during which operating conditions were maintained for 267 hours. Corrosion rates based on 267 hours.

scheduled for the pilot plant. A sulfide corrosion cracking test method, described by Fraser and Treseder,[1] was used to evaluate the environment. A few specimens and a test holder are shown in Figure 4.

Most of the alloys used in the pilot plant test were previously tested in the laboratory by Fraser and Treseder. For each alloy a series of laboratory tests were run in one environment over a range of stress values. The stress at which the probability of failure by cracking is 50 percent was taken as the resistance to cracking. This stress, known as the critical stress, S_c, was calculated from the laboratory corrosion test data using a numerical method. A low S_c value indicates that an alloy will crack at low stress; a high value indicates it would crack at high stress.

By field testing a variety of alloys at a common stress level, it was possible to characterize the environment in terms of the S_c value of the most susceptible alloy which did not show cracking. All

TABLE 5—Corrosion Summary of Carbon Steel Under Inhibited Conditions in Hydrogen Sulfide-Water Absorption Pilot Plant

COUPON LOCATION	Exposure in Hours	Uninhibited Corrosion in MPY[1]	INHIBITOR			
			A		B	
			Corrosion Rate in MPY	Percent Decline	Corrosion Rate in MPY	Percent Decline
1 Absorber Top.............	26	95	..	..	49	48
	33	80	39	52	..	..
4 Absorber 4th Section........	26	130	..	..	49	54
	33	105	9	91	..	..
6 Absorber Bottom...........	1	1055	132	87		
	26	160	..	..	76	53
	32	140	12	91	..	..
9 Flash Tank.................	26	76	..	..	83	Nil
	33	75	4	95	..	..

[1] Uninhibited corrosion rates estimated from Figure 3.

EXPOSURE TIME IN HOURS

Figure 6—Inhibited and uninhibited carbon steel corrosion rates in hydrogen sulfide-water absorption pilot plant.

alloys used in the plant test were stressed to 120,000 psi nominal outer fiber stress. Table 3 summarizes the cracking test results. This is a high stress chosen so all alloys would be uniformly strained and so as to ensure cracking of susceptible alloys.

Based on these results the environment might be characterized in terms of an S_c value of about 9.0. In general, alloys of higher susceptibility failed (S_c below 9.0) while alloys of less susceptibility (S_c above 9.0) survived.

Alloy Corrosion

Corrosion test specimens of various alloys also were installed in the absorber top and bottom sections to determine the best metals from a weight loss standpoint for this environment. The results of these tests are shown in Table 4. All specimens exhibited general surface roughening, so the maximum penetration rate was about twice the indicated corrosion rate.

The seven alloys at the top of the list experienced general corrosion rates of less than one mil per year. Three of these seven, namely stainless steel Type 304, Inconel, and K-Monel, also were tested and found resistant to sulfide corrosion cracking as previously shown in Table 3. Fraser and Treseder[2] previously found in laboratory tests that austenitic stainless steels, Monel, K-Monel, and Stellite were resistant to this type of failure, but that precipitation-hardening and heat-treatable grades of stainless steels were susceptible to cracking.

Hydrogen Probes

A hydrogen probe was mounted in the absorber bottom and at the liquid level in the degasifying drum. These probes were installed to measure the hydrogen penetration rate during the test period.[3] Figure 5 shows the probe pressure build-up experienced during 18 operating days. The rate of pressure increase was approximately one pound per square inch daily in the absorber probe during the last nine days of the test. In the degasifying drum the probe pressure was about three pounds per square inch daily during the last eight days of plant operation. When compared to pressure build-up of about 23 psig daily during the first five days, and about 10 psig daily during the second five-day period, it is in-

dicative of a decline in the corrosion causing hydrogen penetration.

This agrees with declining corrosion rates reported for the carbon steel weight loss coupons.

Inhibition

Laboratory experiments by Shell Development Company indicated three inhibitors which might reduce corrosion in this environment. Therefore, two short periods were devoted to obtaining corrosion measurements under inhibited conditions. Two organic film forming inhibitors were tested at a concentration of about 0.1 percent by volume.

A summary of these results is shown in Table 5. Inhibitor A, a water dispersable, amine type inhibitor, was more effective in each exposure point than B, a water soluble, oil insoluble, imidazoline type inhibitor. In addition, all coupons exposed while testing inhibitor B were blistered, whereas no coupon exposed during inhibitor A test became blistered. Figure 6 shows carbon steel corrosion rates in the absorber bottom for the uninhibited condition and while using inhibitor A.

A few sulfide corrosion cracking coupons were exposed in the pilot plant filter under both inhibited and uninhibited conditions. Table 6 summarizes these results and indicates that inhibitor A also is effective in reducing the severity of the environment from a cracking standpoint. Although the exposure time of the cracking tests was much shorter during the inhibitor runs, laboratory experience has shown with few exceptions that test specimens which fail do so within a few days.[1]

Neither inhibitor tended to promote foaming; however, inhibitor B tended to slightly reduce the absorption of hydrogen sulfide in water.

Pilot Plant Failures

During the pilot plant operation a Bourden tube and several relief and pump valve springs failed through brittleness. Inasmuch as these items were
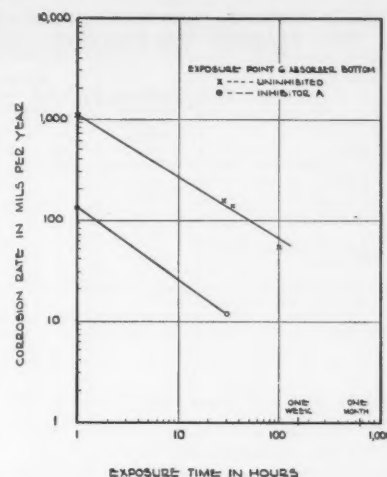
TABLE 6—Sulfide Corrosion Cracking Results in Hydrogen Sulfide-Water Absorption Pilot Plant Under Inhibited Conditions

ALLOY	Relative Cracking Suscepti- bility S_c	COUPON LOCATION*			
		Uninhibited			Inhibi- tor A Filter[3]
		Abs. Top[1]	Abs. Btm.[1]	Filter[2]	
SAE 4340	2.1	F, F	M	..	S
12 Cr. Wrought	4.0	..	..	..	S
9 Cr. 1 Mo.	5.2	F	M, M	F, F	S
Welded Carbon Steel	> 17	..	..	S, S	S
304	> 17	..	S	S, S	..
Firebox Plate Steel ASTM 285, Gr. C	> 17	..	..	S, S	S

*Code to letters is as follows:
S—Survived, F—Failed, M—Missing, assumed failed. Exposure time in operating hours [1]—267 hours, [2]—142 hours, [3]—33 hours.

made of hard materials, susceptible to sulfide corrosion cracking, and highly stressed in the test, failure was not unexpected.

Conclusions

The conclusions drawn from these tests are:

1. Uninhibited corrosion rates of carbon steel, though initially high, are apparently stifled rapidly by formation of a heavy layer of iron sulfide in the absorber and rich solution line. Similar protection is developed in the flash drum, but at a slower rate.

2. Hydrogen blistering, as observed on numerous carbon steel coupons and as indicated by pressure build-up on two hydrogen probes, can occur in this environment. Killed carbon steel could be used in vessels and piping to reduce the susceptibility to attack of this type.

3. Sulfide corrosion cracking is a potential problem in this environment. Materials should be chosen which have low susceptibility to cracking and all vessels and welds should be stress relieved. Use of an inhibitor is indicated.

4. Inhibition with inhibitor A appears very attractive inasmuch as weight loss corrosion, hydrogen blistering and sulfide corrosion cracking were all reduced when the absorption water contained 0.1 percent by volume of this inhibitor.

5. Inasmuch as these conclusions on inhibition are based on short term tests, they may not be completely reliable. The stability of the iron sulfide film under inhibited conditions would have to be determined. The effect of iron-iron sulfide couples also would require study. Likewise, it would be necessary to observe the influence of chloride concentration in the absorption water on various forms of corrosion damage.

Proposed Corrosion Control Methods

As a result of these tests, together with experiences

of others, the following provisions might be considered for corrosion control in a commercial plant:

1. Pump parts should be highly resistant to this environment since velocity effects will tend to remove any corrosion products formed. Stainless steel Type 304 or 316 should be satisfactory for service in pump casings, impellers, and shafts. Stellite No. 1 over 316 should be satisfactory for shaft sleeves and casing rings. K-Monel should be suitable for impeller rings. Mechanical seal parts, such as the rotating elements, locks, and glands, could be made of 316. Inserts could be carbon with K-Monel springs. Valve trim, thermometer wells, and orifice plates should be of a corrosion resistant material such as 316. Pressure gauge Bourdon tubes used in this service should be of K-Monel. Relief valve springs should be K-Monel or possibly aluminized spring steel which was not tested in the pilot plant.

2. From the standpoint of atmospheric corrosion by intermittent exposure to low concentrations of hydrogen sulfide and sulfur dioxide around a plant of this type, potentiometer cases should be airtight and provided for air purging to protect copper contacts and wiring. Hermetically sealing of arcing relays and oil immersion of slide wires could provide protection from atmospheric corrosion as well as providing safety features. Motor controllers should be oil immersed for the same reasons. The electric power distribution board should be located remotely to the gas processing area and would require protective lacquer or grease coatings on all copper components to reduce atmospheric corrosion.

Aluminum conduit and instrument tubing would provide corrosion resistance to this atmosphere. Aluminum building trim and fencing could be used for the same purpose. Sheet aluminum or asbestos-cement sheet buildings would provide long term service in this environment.

References

1. J. P. Fraser, and R. S. Treseder. Resistance of Tubular Materials to Sulfide Corrosion Cracking, *Transactions ASME,* **77,** 817-826 (1955) Aug.

2. J. P. Fraser, and R. S. Treseder, Company report.

3. R. T. Effinger, M. L. Renquist, A. Wachter, and J. G. Wilson. Hydrogen Attack of Steel in Refinery Equipment, *Proc. API,* 31 M (III), 107-33 (1951).

The Effect of Dissolved Oxygen on Corrosion of Steel And on Current Required for Cathodic Protection*

By E. SCHASCHL and G. A. MARSH

Introduction

DISSOLVED OXYGEN is properly recognized as an important factor in the corrosion of steel. As a result of its function as an effective cathodic depolarizer, it controls the corrosion rate of steel in aqueous solutions. The relationship between dissolved oxygen concentration and corrosion rate frequently has been considered as linear in the range below 7 or 8 ppm.[1, 2, 3, 4]

The effect of dissolved oxygen has been given some attention in connection with cathodic protection current density requirement. Thompson[5] observed that the degree of protection was proportional to the amount of current supplied, and Clement and Walker[6] pointed out that protective current density requirement increased with increasing dissolved oxygen concentration. Sudrabin[7] reported that protective current density varied directly with dissolved oxygen concentration and was independent of the pH and electrolyte composition in the neutral range. Comeaux[8] considered that all of the current supplied for cathodic protection of certain buried structures reduced dissolved oxygen. He was able to compute a thickness for the diffusion layer associated with transfer of oxygen through the soil.

The present work was undertaken to provide quantitative information on the relationship between dissolved oxygen concentration, corrosion rate, electrode potential, and minimum current required for cathodic protection. The systems studied were steel in synthetic laboratory electrolytes. It was felt that the data would be more readily interpreted in this way than if complex natural systems were used.

Measurement of Corrosion Rates

Corrosion tests were all of short duration, one to several days. Instead of coupons, temperature compensated steel corrosion probes were used (Figure 1), as described in previous communications from these laboratories.[9, 10, 11] This probe technique permitted direct reading of the corrosion loss while the test specimen (probe) was installed in the corrosive environment. The corrosion rates so obtained were computed in units of microinches (millionths of an inch) loss of thickness per hour. One microinch per hour equals 0.00875 inch penetration per year.

The use of these test specimens or probes has the advantage that one can make direct observation of corrosion rate while corrosion is in progress without interrupting the test. As in any test using small specimens, the corrosion rates observed may not be

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Abstract

The interrelationship of corrosion rate of steel, dissolved oxygen concentration, agitation, electrode potential, and cathodic protection current density were studied under controlled laboratory conditions. While the corrosion rate of steel is essentially linear with amount of dissolved oxygen, the rate appears to fall almost to zero near 1.0 ppm dissolved oxygen rather than at zero ppm dissolved oxygen as commonly assumed. In the region below 2 ppm dissolved oxygen, there is almost no effect of agitation on corrosion rate; above 2 ppm there is a large effect. By measuring the corrosion rate of an unprotected specimen, it should be possible to compute the minimum current density needed for cathodic protection in the field.

In acidic environments, less current is needed for protection than is predicted by analysis of the mechanism of cathodic protection. This fact suggests that the anodic reaction in low pH corrosion proceeds by the removal of "chunks" of metal which contain several atoms. The "chunk effect" also appears to operate in the neutral range, but only when the corrosion rate is very high.

The effect of differential aeration on corrosion rates is discussed in detail.   5.2.4

identical to those of large structures in the same environment. However, the use of probes leads to a self consistent set of data which should be generally applicable.

The particular probes used were 3 x 0.125 x 0.001
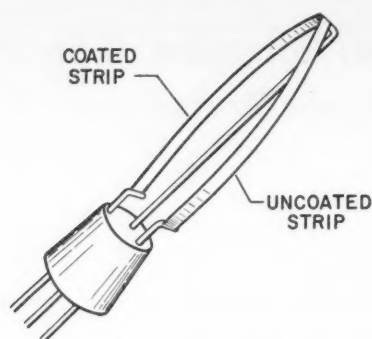
Figure 1—Temperature compensated probe.
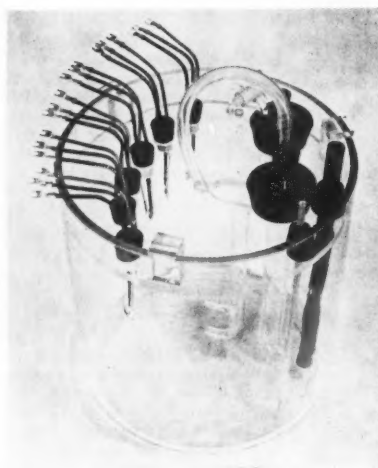
Figure 2—Experimental setup.
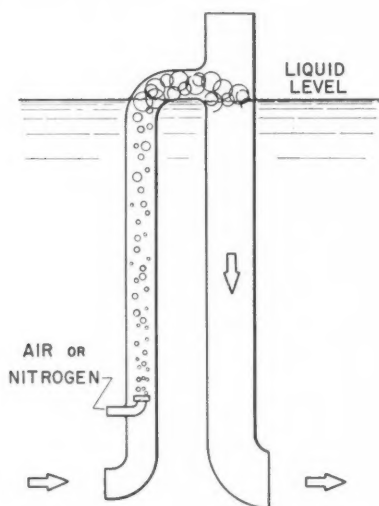
Figure 3—Bubbler used to maintain constant degree of aeration.

inch cold rolled steel. They were pretreated by momentary immersion in dilute hydrochloric acid followed by thorough rinsing in water, just prior to use in the experiments. Readings were made with an

AC bridge type corrosion meter[9] as often as needed to establish the corrosion rate.

In a typical experiment, six probes were held on a plastic plate equidistant from a carbon rod anode. The probes and anode were immersed in a glass battery jar 12 inches in diameter by 12 inches high (see Figure 2.) A saturated calomel half cell also was inserted through the plastic plate, close to the probes. By means of a dry cell and resistors, current could be passed through each probe independently; this current could be adjusted over wide limits and measured using a vacuum tube voltmeter. The vacuum tube voltmeter also was used to determine the electrode potential of the probes referred to the calomel half cell. This assembly permitted the simultaneous measurement of electrode potential, corrosion loss of thickness, and cathodic protection current density.

Measurement of Dissolved Oxygen and pH

Rapid measurements of dissolved oxygen concentration were made amperometrically by means of a calibrated rotating platinum electrode.[12] In solutions of low conductivity, solid sodium chloride was added. The accuracy of dissolved oxygen determinations was about ±5 percent, using the Winkler test as a standard.

The dissolved oxygen concentration was controlled by the use of bubblers as shown in Figure 3. Air and nitrogen of constant ratio were passed through the bubblers to maintain a steady dissolved oxygen concentration. With this system the dissolved oxygen concentration could be adjusted from the value in equilibrium with air at atmospheric pressure down to about 1.5 ppm. The design of the bubblers also minimized agitation; the measured velocity of particles in the tanks was less than 0.2 inch per second. Where desired, a greater degree of agitation could be provided. Also, the range below 1.5 ppm dissolved oxygen could be explored by using a closed system.

All electrolytes used were buffered by standard methods. The use of phosphate buffer was avoided because of its action as a corrosion inhibitor.[13] The pH of the electrolytes was measured using a glass electrode pH meter. The principal electrolyte used was 3 percent sodium chloride solution.

Corrosion Rate as a Function of Dissolved Oxygen Concentration

Figures 4 and 5 show data obtained on the effect of dissolved oxygen on corrosion rate. The solutions used were 3 percent NaCl buffered to various pH values. The temperature in each case was 80 F. The data of Figure 4 are for essentially static solutions, while those of Figure 5 are for solutions agitated to provide a velocity of about 5 feet per second.

The data of Figures 4 and 5 do not fall on a smooth curve. The deviation from the average was most pronounced in the pH 8.3 solutions having low corrosion rates. The higher the corrosion rate, the more reproducible were the corrosion rate data. As
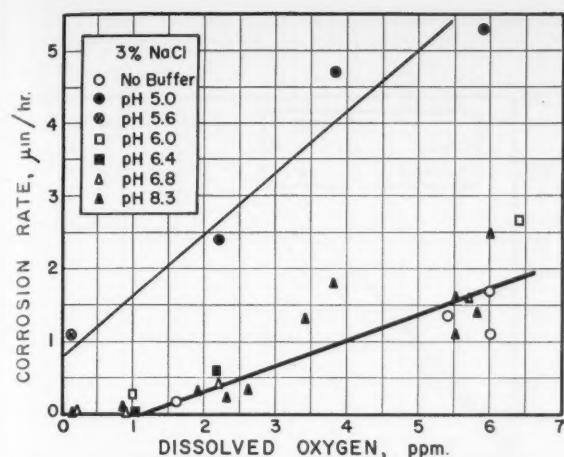
Figure 4—Corrosion rate of steel as a function of dissolved oxygen concentration (static solutions).
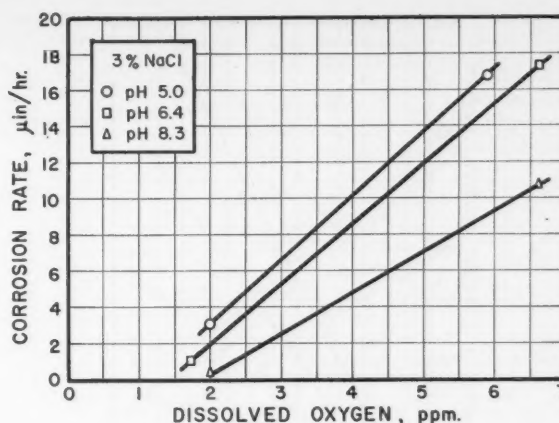
Figure 5—Corrosion rate of steel as a function of dissolved oxygen concentration (agitated solutions).

the acidity increased the reproducibility also increased; in dilute acid solutions it was found that the corrosion rates as measured with probes were reproducible within 5 percent.

Figure 4 shows that by increasing the dissolved oxygen concentration from 1.5 to 7 ppm, the corrosion rate was increased from about 0 to about 2 microinches per hour (0.0175 inch per year). This rate was attained in solutions of pH 6.4 and higher. There was no significant effect of pH between 6.4 and 8.3. Also, in this pH range, the corrosion rate became very small below 1.5 ppm dissolved oxygen.

At pH 5, however, the accelerating effect of dissolved oxygen was even more pronounced as shown on Figure 4. There was an abrupt change in mechanism of the cathodic reaction, probably at about pH 5.5. At any given dissolved oxygen concentration the corrosion rate at pH 5 was three or four times the rate at pH 6 and higher.

Figure 5 shows quantitatively the importance of agitation in aerated solutions. In the agitated solution of pH 5, the corrosion rate increased from 3 to 16 microinches per hour with a 4 ppm increase in dissolved oxygen. In solutions of other pH the effect was equally spectacular. At pH 8.3, for example, the agitated solution containing 2 ppm dissolved oxygen yielded a low corrosion rate of a few tenths of a microinch per hour; when the dissolved oxygen concentration was tripled, the corrosion rate increased more than 50 fold.

It is interesting to note that corrosion rates of 17 microinches per hour (0.15 inch per year) and perhaps higher, can be attained in aerated neutral solutions, with moderate agitation.

Another important feature of these data is that agitation has little or no effect on corrosion rate if the dissolved oxygen concentration is less than about 2 ppm. Agitation has a direct effect on diffusion. These facts suggest that a minimum oxygen concentration of 1-1.5 ppm is necessary at the cathode surface before the oxygen can be chemically reduced.

Cox and Roetheli[2] reported linearity between cor-

rosion rate and dissolved oxygen concentration below 5.5 cc per liter (7 ppm). However, they did not carry out experiments in the region below 4 ppm but merely extrapolated back to the origin. Their actual data points for a static solution fall close to the curve shown in Figure 4. Speller and Kendall[4] also considered that the corrosion rate was linear down to zero concentration and showed long term data obtained in water pipes. Their extrapolated curve indicates a substantial corrosion rate in the region below 1 ppm oxygen, which the authors of this paper have not observed.

Effect of Conductivity

The data of Figures 4 and 5 are for 3 percent NaCl solutions. A large number of additional data were obtained under static conditions with distilled water buffered to various pH values between 6 and 8.3, and with other dilute NaCl solutions similarly buffered. Dissolved oxygen was maintained at various levels from 1.5 to 6.5 ppm. The data clustered around the same curve as that of Figure 5. The indications were that the mechanism of corrosion started to change from cathodic control to resistance control at a conductivity of about 0.1 reciprocal ohm meter. This conductivity was attained with neutral dissolved solids of the order of 100 ppm. In solutions of greater dissolved solids content, the corrosion rate was entirely dependent on dissolved oxygen concentration rather than pH or conductivity.

Effect of Dissolved Oxygen on Minimum Current Required for Cathodic Protection

Figure 6 presents smooth curves depicting the minimum current needed as a function of dissolved oxygen concentration. As Sudrabin[7] has pointed out, minimum current is essentially linear with dissolved oxygen. However, the minimum current drops to 0 near 1 ppm, rather than at 0 ppm.

Figure 6 illustrates the extreme range of protective currents in aqueous solutions—150 ma/sq ft may be
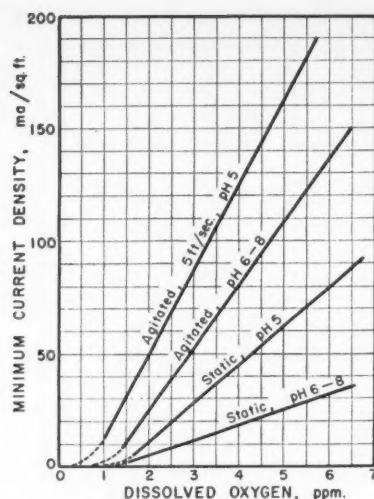
Figure 6—Minimum current needed to protect steel in aqueous solutions of various pH and degrees of agitation.

Figure 7—Relationship between corrosion rate without protection and minimum current density needed for cathodic protection.

needed to protect steel in agitated, aerated neutral water. Even in a static system, a protective current of 30 ma/sq ft may be needed if dissolved oxygen is maintained at a 6 ppm level. The fact is that much lower current densities are often sufficient in practice. This is explained by the difficulty of maintaining a high degree of aeration in most natural environments. Also, as shown by Sudrabin and Marks,[14] a film or deposit of calcium or magnesium salts can decrease the minimum current to a low value.

Relationship Between Minimum Current Density and Corrosion Rate

According to Sudrabin and Marks' analysis,[14] based on an electrical analogy of Pearson,[15] a consistent proportionality between corrosion rate and protective current does not exist. Schwerdtfeger and McDorman,[16] however, concluded from electrolytic measurements that there is a relatively fixed relationship between corrosion rate of steel in soils and the current required for cathodic protection. Denison and Romanoff[17] also observed a correspondence between corrosion current (which is proportional to corrosion rate) and protective current density. Holler[18] showed that corrosion current can be related to cathodic protection current if cathodic polarization data are known.

The technique used in making the studies reported here proved to be a convenient method for establishing if there is a correlation between minimum current density and corrosion rate. The procedure was to allow a probe to corrode in an environment maintained as constant as possible. After a corrosion rate had been established, a measured current was applied and the minimum current achieving full protection was noted. As a check, the current could be interrupted. This would restore the corrosion rate, which in the authors' solutions was usually identical to the original rate.

Figure 7 shows the results of this study. With a
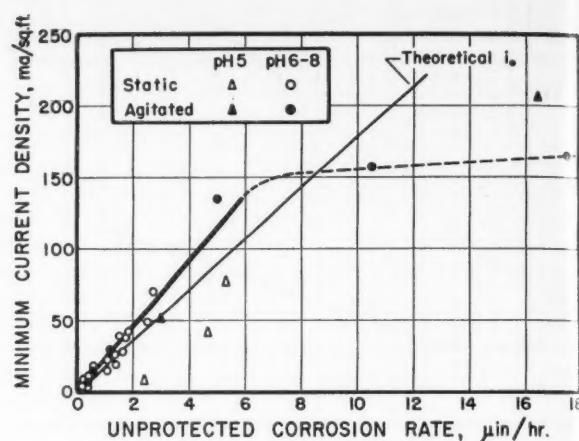
few exceptions, which will be discussed, the data points fall near a straight line. This straight line defines the theoretical corrosion current (i.e., the current which flows in the local cells in accordance with Faraday's Law).

Examination of Figure 7 led to the conclusion that in solutions of pH 6-8.3, the minimum current needed for cathodic protection is approximately equal to the corrosion current. This relationship is not significantly affected by pH between 6 and 8.3, nor by dissolved oxygen concentration, conductivity, or agitation, up to a corrosion rate of 6 microinches per hour.

The data can be tabulated in a form suitable for studying the minimum protective current/corrosion current ratio (I_p/i_o). The corrosion current i_o for any corrosion rate U can be obtained from the relationship:

$$i_o = 17.8\ U \tag{1}$$

where i_o is in ma/sq ft and U is in microinches penetration of steel per hour.

Table 1 tabulates I_p/i_o for the data of this paper and also for a number of other data given in the literature.[16, 18, 19, 20, 21, 22] The most consistent data were from the long term tests of Schwerdtfeger and McDorman,[16] where I_p/i_o was about 1.15. The average value of I_p/i_o for the present paper (pH 8.3 runs) was 1.12, although there was considerable scatter of the data. The deviation from the average was most pronounced at very low corrosion rates where reproducibility was poorest. In the pH 6-7 runs, the average I_p/i_o was 1.36. From polarization data alone, Holler[18] found an I_p/i_o ratio of 1.33.

The variations in I_p/i_o as seen in Table 1 for pH 6-8.3 data are believed to be due to experimental difficulties in obtaining U and I_p, rather than due to inherent inconstancy of the ratio.

It is evident that, in the neutral pH range where

TABLE 1—Ratio of I_p/i_o Calculated From Various Literature Sources

Reference	Electrolyte	Corrosion Rate, μ in. per hr.	Min. Current Density, ma. per sq. ft.	I_p/i_o	Remarks
This paper	3% NaCl, pH 8.3, various D.O. and degrees of agitation.	2.5 1.4 1.1 0.33 1.6 1.8 1.5 0.23 0.28 0.35	49 19 15 3 28 42 39 8.5 10 6.5	1.10 0.74 0.75 0.51 0.98 1.31 1.45 2.07 2.00 1.04	
			Average	1.12	
This paper	3% NaCl, various buffered pH between 6 and 7.5	1.35 0.17 1.7 1.10 1.6 5.0 0.42 0.57 2.7 0.6 1.2	26 5 38 22 39 135 11 14 70 15 2.8	1.10 1.64 1.25 1.12 1.37 1.51 1.47 1.38 1.45 1.40 1.30	
			Average	1.36	
Schwerdtfeger & McDorman[16]	Various soils	*	*	1.25 1.20 1.20 1.15 1.10 1.15	*S. & McD. give calculated i_o and I_p derived from polarization data. The values of I_p/i_o shown here were calculated from their experimental weight loss data.
Hill[22]	0.1 N NaCl 0.1 N Na₂SO₄ Sea water	0.38 0.36 0.44	15 12 10	2.2 1.8 1.3	Data for corrosion rate and min. current are approximate.
May and LaQue[21]	Sea water, velocity 7.8 ft. per sec.	6.0	150	1.4	
Kehn and Wilhelm[20]	500 ppm Na₂SO₄ 500 ppm NaCl	0.23 0.21	7.4 10.0	1.8 2.6	Corrosion rates obtained from colorimetric data.
Holler[18]				1.33	I_p/i_o obtained from polarization data for Fe/Fe₃O₄ couple.
This paper	3% NaCl, pH5	4.7 3.0 2.4 4.5 16.5	42 52 9 78 208	0.5 0.96 0.21 0.97 0.71	
			Average	0.67	
Pourbaix[19]	N H₂SO₄, pH 0.83	252	285	0.06	
This paper	3% NaCl, pH 6.4 3% NaCl, pH 8.3 (both solutions highly agitated, 6.6 ppm D.O.)	17.5 11.0	166 157	0.53 0.80	These data were reproducible within 10%.

dissolved oxygen is the controlling factor in corrosion of steel, the corrosion rate can be approximated by the relationship:

$$U = \frac{I_p}{1.2 \times 17.8} = \frac{I_p}{24} \qquad (2)$$

where U is corrosion rate without cathodic protection, in microinches per hour, and I_p is minimum cathodic protection current in ma/sq ft. This holds up to a corrosion rate of 6 microinches per hour (0.053 inch per year).

Equation 2 can be useful in approximating the corrosion rate of steel in neutral systems such as water or soils. A device has been built in these laboratories which makes use of Equation 2 to obtain a rapid approximation of corrosion rate in neutral solutions under cathodic control. In operation, increasing cathodic current is applied to a steel electrode until its electrode potential indicates that the minimum current for cathodic protection has been obtained. The applied current is then noted and converted to corrosion rate. The factor 1.2, which is the

Figure 8—Analysis of concept of minimum current density.

average experimental I_p/i_o, and the electrode area, are taken into account so that the meter face reads directly in corrosion rate.

Minimum Current Density

The minimum current density has been interpreted as the current which polarizes the local cathodes to the open circuit potential of the anodes. It would appear that I_p must at least equal i_o. The reason for this is seen in Figure 8. The cathodic area C during normal corrosion receives current i_o from the anodic area A. If an external anode A′ is substituted for A, it must supply at least the same current as A normally supplies, before the current from A can be completely suppressed. Any less current than i_o from A′ will permit some current to flow from A, as C has no way of knowing where the current is coming from. More current may be required than i_o to suppress the current from A, if C does not polarize uniformly with cathodic current. As a matter of fact, Mears[23] states that cases are known where I_p is 100 times i_o.

From the above analysis, I_p should be equal to or greater than i_o. Examination of the data (Table 1) however, reveals that the ratio I_p/i_o actually can be less than unity. In pH 8.3 runs, a few low corrosion rate experiments were found in which this occurred; however, these were the first runs made and it is likely that deviation from unity was experimental error. Later experiments at high agitation and high dissolved oxygen showed that I_p/i_o actually fell below unity at corrosion rates above 6 microinches per hour.

In the pH 5 runs, too, the average I_p/i_o ratio was only 0.67, and not one run was made in which the ratio was unity or greater. Pourbaix[19] gave data at

Figure 9—Relationship between Britton curve and the corrosion rate—
applied current curve.

pH 0.83 which calculates out to an I_p/i_o ratio of only 0.06.

Below pH 5.5, the mechanism of corrosion changes primarily from oxygen control to hydrogen control. The data indicate that this change in cathode mechanism is accompanied by a fundamental change in the anode process. A possible explanation of the data is that, below pH 5.5, corrosion proceeds by the removal of "chunks" of iron rather than by removal of one atom at a time. The chunks may consist of several atoms which have been loosened from the parent metal by undermining. In this way the corrosion rate is higher than the equivalent corrosion current. The same phenomenon may occur at high corrosion rates in solutions of pH 6-8.3.

Relationship Between Electrode Potential, Current Density, and Corrosion Rate

The experimental technique permitted measurements of all of these variables simultaneously on the same piece of steel. (Strictly speaking, corrosion rate was obtained over a time interval of at least one half hour.) The electrode potential of freely corroding steel probes varied from —0.45 to —0.68 volt versus a saturated calomel half cell. Figure 9 shows a typical plot of electrode potential ("Britton curve") and corrosion rate as a function of applied current density.

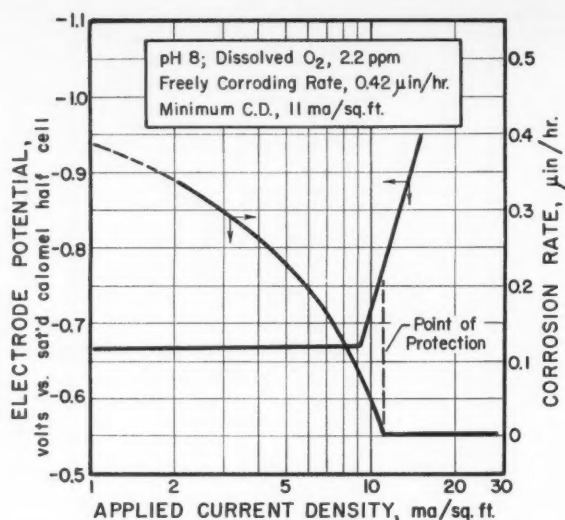The electrode potential was practically constant until a current near the minimum protective current was applied. At higher current densities, the electrode potential was linear with the log of current density. According to Evans, Bannister, and Britton,[24] the break in the curve corresponds to minimum current density. The authors of the present paper found, as did Kehn and Wilhelm,[20] that protection occurred at a higher current density than indicated by the Britton curve (in the example shown this was 11 ma/sq ft versus 9 ma/sq ft). The current density at

the point of protection corresponds to a potential of —0.77 volt versus saturated calomel.

It will be noted that there is an equally sharp break in both the Britton curve and the corrosion rate-potential curve. While the corrosion rate is shown on Figure 9 as zero once the minimum protective current is reached, there is a very slight corrosion rate which persists even at high protective currents.

In obtaining data for this paper, it was found that potential measurements were more difficult to make with certainty than corrosion measurements. For this reason, it is believed that where applicable, a more accurate approach to cathodic protection might be to measure the freely corroding rate and to calculate the applied current from Equation 2. Assurance would be needed that the corrosion rate of the measured corrosion specimen was approximately that of the structure to be protected. The best method would be to use thick probes which could be installed and left in place for long periods.

A possible experimental arrangement is shown in Figure 10. A probe is buried near the structure to be protected. Initial probe readings with the probe and structure unprotected serve as the basis for applying current, using Equation 2. This Equation 2 current density is applied to both the probe and structure. Meters M_s and M_p show the current.

After a period of time, the probe reading is again taken, to see if the applied current has been sufficient to protect the probe. If this current has not been sufficient, suitable current increase can then be made on both probe and structure. On the other hand, the probe may be completely protected or even overprotected; this is the more likely possibility. Overprotection may be due to so-called polarization or the formation of deposits on the metal surface during the time current was being supplied. The proper current for protection can now be found by interrupting the current to the probe and again obtaining the freely corroding rate. This new rate now becomes the basis for applying Equation 2 current to the structure. Using this method, it may be possible to apply proper current to the structure without making potential measurements or soil surveys. The effect, however, of long cell action or bacterial depolarization probably would not be detected.

Differential Aeration

Comeaux[8] suggested that diffusion of oxygen through soil could set up differential aeration cells between the top and bottom of a buried pipe. To study this possibility and also to study the effect of differential aeration in general, additional experiments were carried out. A vessel 12 inches in diameter by 12 inches deep was set up as shown in Figure 11, using sand as a porous medium. One series of probes were spaced vertically in the vessel to measure the normal corrosion rate at the various levels. Another series of probes were spaced at the same levels as the probes of the first series, but were electrically connected together. The experiment was similar to the well known piling experiments of Humble, Larabee, and LaQue.[25] The use of probes
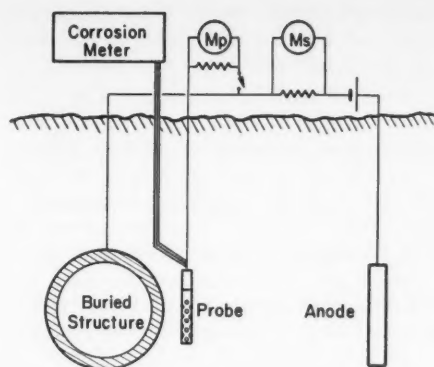
Figure 10—Apparatus to check corrosion rate
and current density of a buried structure.

Figure 11—Apparatus used to test differential
aeration.

permitted continuous measurements to be made, so that effects of differential aeration could be observed over short periods of time.

The vessel was filled with sand after the probes were in place. This effected a sharp boundary between aerated and deaerated electrolyte in the test vessel. By means of drains and immersed tubes, it was possible to change the degree of aeration from top to bottom either gradually or abruptly, as desired. The oxygen content at various levels also could be measured if desired by extracting a small sample.

When a 3 percent NaCl solution was circulated uniformly through the sand by percolation, the corrosion rate was uniform on the two vertical series of probes. There was no appreciable difference in corrosion rate from top to bottom, nor from connected to unconnected probes. The corrosion rates, of course, were dependent on dissolved oxygen content in the circulating solution. In pH 8 solution, containing 1.5 ppm dissolved oxygen, the corrosion rate was 0.3 microinch per hour. In a pH 8 solution containing 6.5 ppm dissolved oxygen, the rate was 4 microinches per hour.

Oxygen Diffusion Through Sand

The next experiment was designed to test oxygen diffusion through the sand. The test involved sand saturated with a static, initially aerated solution containing 6.5 ppm dissolved oxygen. The system was open to the atmosphere. The unconnected probes started corroding at 3 microinches per hour and dropped in corrosion rate until after four days the rates (microinch per hour) were, from top probe to bottom, 0, 0, 0.02, 0.04. The connected probes similarly dropped to 0, 0, 0.03, 0.02. The bulk dissolved oxygen concentration at the bottom at this time was 3 ppm.

If there was rapid diffusion of oxygen from the air interface down through the water-saturated sand, the corrosion rate of the uppermost unconnected probe would have remained at about 3 microinches per hour. The sand presented an effective diffusion barrier.

Using Fick's Law, it may be shown that the steady state corrosion rate of steel, U, in microinches per hour can be related to dissolved oxygen concentration gradient $\frac{\Delta c}{d}$ in the units of ppm per inch, by the expression:
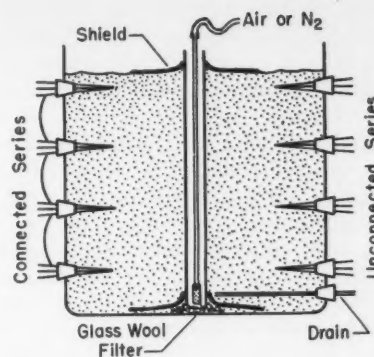
$$U = 12.4 \times 10^{-3} \frac{\Delta c}{d} \qquad (3)$$

In the case of steel in an air-saturated static aqueous solution (say 3 percent NaCl), Δc is apparently about 5 ppm (i.e., 6.5-1.5). According to Hickling,[26] d in such a case is 0.012 inch. From this, U=2 microinches per hour, which is in agreement with the data of Figure 4. This is a steady state diffusion process.

In the case of steel in a 1.5 ppm dissolved oxygen solution in contact with sand, where the steel is located in the position of the uppermost unconnected probe, Δc is again 5 ppm, but the diffusion layer d is difficult to picture physically. An unsteady state exists, so that Equation 3 is not applicable. For example, taking d as the distance from probe to air interface, and allowing a factor for tortuosity which affects diffusion through the sand, U turns out to be 0.03 microinch per hour by Equation 3. The long term corrosion rate is actually 0.18 microinch per hour under these conditions. There does not seem to be a rigorous theoretical approach to determining corrosion rate by oxygen diffusion through porous media at this time. However, it is expected that future research will change this picture.

Saturation of Sand With Brine

Another experiment was carried out in which the sand surrounding the upper three probes of each series was saturated with brine containing 6.5 ppm dissolved oxygen. The sand surrounding the bottom probe of each series was saturated with brine containing only 1.5 ppm dissolved oxygen. The brine was static. In the unconnected series, the upper probes initially corroded at 3 microinches per hour; the bottom probe corroded at a very low rate. In the connected series, the upper probes corroded initially at 1.5 microinches per hour; the bottom connected probe corroded slightly faster than the bottom unconnected probe but still at a hardly measurable rate. This shows that differential aera-

tion is only slightly operable in static conditions where a diffusion barrier such as sand surrounds the steel. This is true even when the dissolved oxygen concentrations at the anodic and cathodic regions are different by 5 ppm.

This experiment suggests another important point: If steel is totally immersed in a medium, such as soil, which is water saturated (i.e. the steel is below the water table), the corrosion rate may be expected to be very low, provided there are no "long" cell effects or bacterial action. It can be seen that, practically speaking, differential aeration cells do not operate under these conditions.

The fact that the initial corrosion rate of the upper probes in this experiment was 3 microinches per hour instead of about 1.5 (cf. Figure 4) is unexpected. As the corrosion is under cathodic control in any case, the limiting factor should be oxygen transfer at the cathode, and the initial corrosion rates in air saturated brine would be expected to be the same regardless of the presence of sand. The increased corrosion rate in sand was quite reproducible, however.

In another set of experiments, using the same setup of Figure 11, 3 percent NaCl solution of pH 7.5 containing 6.5 ppm dissolved oxygen was used to saturate the sand. When this was left as a static system for several days, the corrosion rates on all probes dropped to the low values as reported above for a similar experiment. Now some of the NaCl solution was drawn from the bottom of the vessel, corresponding to a lowering of the water table. As soon as the upper probe of each series was above the water table, the corrosion rates changed as follows:

Probe No.		Connected Series	Unconnected Series
(Top)	1	2.1 μ in./hr.	10.7 μ in./hr.
	2	5.3	0
	3	4.9	0
(Bottom)	4	3.7	0

In the connected series, the upper probe was now intimately associated with dissolved oxygen even though surrounded by sand, and it acted as a cathode for the connected probes below it.

The cathodic current density going to the upper connected probe (when the probe was above the water table) was sufficient to decrease the corrosion rate from 10.7 microinches per hour as in the unconnected top probe to 2.1 microinches per hour. The anodic current density from the lower probes should have been sufficient to protect completely the upper probe if the anodic current was proportional to corrosion rate. It appears that the anodic current was appreciably less than that based on Faraday's Law. This could possibly be explained by the "chunk effect" mentioned earlier in this paper.

The extremely high rate on the top unconnected probe is especially interesting when it is recalled that steel corrodes at only about 1.5 microinches per hour in air-saturated 3 percent NaCl (Figure 4) or 3 microinches per hour in sand saturated with aerated 3 percent NaCl. Drained sand is especially corrosive because the steel is in contact with a large area of thin water film which serves as a continuous electrolyte but which offers little barrier to transfer of oxygen from the air.

The effect of differential aeration is slight in a static water-saturated sand even when the anode and cathode are exposed to widely different dissolved oxygen concentrations. There is also a very low corrosion rate in a static, air-saturated system in which steel is totally immersed in a water-saturated diffusion barrier such as sand. Drainage of water around a buried structure plays an important role in differential aeration. The most drastic effect of differential aeration seems to be in the case where a structure is buried at the water table.

Conclusions

The corrosion rate of steel in neutral aqueous solutions is determined by the dissolved oxygen content available at the surface of the steel. Any factor affecting diffusion of oxygen will have a marked effect on corrosion rate.

While the corrosion rate of steel is essentially linear with dissolved oxygen, it appears to fall almost to zero near 1.0 ppm instead of at zero ppm dissolved oxygen as commonly assumed. Therefore it is not necessary to deaerate completely in order to provide a low corrosion rate. In the region below 2 ppm dissolved oxygen, there is almost no effect of agitation on corrosion rate; above 2 ppm there is a large effect.

In neutral environments, the minimum current density needed for protection is about 20 percent greater than the current associated with corrosion. By measuring the corrosion rate of an unprotected specimen, it should be possible to compute the minimum current density needed for cathodic protection in the field.

In acidic environments less current is needed for protection than is predicted by analysis of the mechanism of cathodic protection. This fact suggests that the anodic reaction in low pH corrosion proceeds by the removal of "chunks" of metal which contain several atoms. The "chunk effect" also appears to operate in the neutral range, but only when the corrosion rate is very high.

Differential aeration is shown to be an important factor in corrosion if a structure is buried at the water table. In a static, liquid-saturated porous system, however, there is no appreciable effect of differential aeration even when the bulk oxygen concentrations at the anodic and cathodic areas are widely different.

NOTE: Some of the novel features of this paper are covered by patent applications in the name of The Pure Oil Company.

References

1. F. J. Speller. Corrosion, Causes and Prevention, Second Edition, McGraw-Hill Book Co., New York, 1935, p. 161.
2. G. L. Cox and B. E. Roetheli. *Ind. Eng. Chem.*, **23**, 1012 (1931)
3. R. E. Wilson. *Ind. Eng. Chem.*, **15**, 125 (1923)
4. F. N. Speller and V. V. Kendall. *Ind. Eng. Chem.*, **15**, 134 (1923)

5. M. DeKay Thompson. *Trans. Electrochem. Soc.,* **69,** 155 (1936)

6. J. K. Clement and L. V. Walker. *Ind. Eng. Chem.,* **5,** 361 (1913)

7. L. P. Sudrabin. *Corrosion,* **2,** 175 (1946)

8. R. V. Comeaux. *Corrosion,* **8,** 305 (1952)

9. G. A. Marsh and E. Schaschl. *Oil and Gas J.,* **54,** No. 29, 135 (1955)

10. G. A. Marsh and A. V. Koebley, Jr. *Oil and Gas J.,* **54,** No. 29, 139 (1955)

11. G. A. Marsh and E. Schaschl. *Corrosion,* **12,** 534 (1956) Nov.

12. G. A. Marsh. *Anal. Chem.,* **23,** 1427 (1951)

13. M. J. Pryor and M. Cohen. *Nature,* **167,** 157 (1951)

14. L. P. Sudrabin and H. C. Marks. *Ind. Eng. Chem.,* **44,** 1786 (1952)

15. J. M. Pearson, in Corrosion Handbook, H. H. Uhlig, editor, pp 923-34, John Wiley & Sons, Inc., New York, 1948

16. W. J. Schwerdtfeger and O. N. McDorman. *J. Electrochem. Soc.,* **99,** 407 (1952)

17. I. A. Denison and M. Romanoff. Research Paper RP 1876, *J. Nat. Bur. Stds.,* **40,** 301 (1948)

18. H. D. Holler. *J. Electrochem. Soc.,* **97,** 277 (1950)

19. M. Pourbaix. *Corrosion,* **5,** 121 (1949)

20. G. R. Kehn and E. J. Wilhelm. *Corrosion,* **7,** 156 (1951)

21. T. P. May and F. L. LaQue. *Corrosion,* **10,** 91 (1954)

22. W. R. Hill. *Petro. Eng.* **12,** No. 13, 51 (1941)

23. R. B. Mears. *Oil and Gas J.,* **46,** No. 12, 77 (1946)

24. U. R. Evans, L. C. Bannister, and S. C. Britton. *Proc. Royal Soc.,* A131, 355 (1931)

25. H A. Humble. *Corrosion,* **5,** 292 (1949). Also Discussion by C. P. Larrabee and F. L. LaQue, *Corrosion* **5,** 301 (1949)

26. A. Hickling. *Quarterly,* **3,** No. 2, 95 (1949)

Any discussions of this article not published above
will appear in the June, 1957 issue.

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Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

Sprayed Metal as a Base for Paints*

By H. S. INGHAM

Introduction

THERE MAY be some question as to why sprayed metal is referred to as a paint *base* when such material usually is sold *instead* of paint? It is true enough that sprayed metal was originally sold as a new coating method, and in some cases it did replace paints of various kinds. In many other cases it replaced the use of bare, uncoated steel. A review of the history of metallizing shows, however, that a great many of the metallized surfaces were actually painted, even though very little emphasis was given to the paint coatings in the early literature.

In the last ten years the emphasis in the metallizing industry has been placed upon combination coatings which consist of a layer of sprayed metal sealed or coated with organic materials such as vinyls, chlorinated rubbers, phenolics, and silicones. These coatings generally are referred to as Metallized System Coatings. The emphasis in such systems has been on the sprayed metal with the organic coatings usually being referred to as "sealers." This is only natural inasmuch as the sprayed metal layer in most cases is of considerable thickness and offers the primary protection. When the sprayed metal is 10 mils thick or more, such coatings offer excellent protection against many severe corrosive environments. Metal coatings of these thicknesses, however, are relatively expensive as compaared with paint coatings. The extensive publicity given the thicker coatings has tended to push into the background the use of thin sprayed metal coatings as a base for paints.

It is true that the difference between thick and thin metal coatings is quantitative, but there are a number of qualitative differences as well. *Thick* sprayed metal coatings are thought of as the primary protective barrier whether or not paints and organic sealers are used. The cost is relatively high and service requirements must justify the expense. Where *thin* coatings (as thin even as 2 to 4 mils) are used as a base or preparation for paint, the story is quite different. The primary protection in this case is from the paint and the primary purpose of the sprayed metal is to enhance and prolong the properties of the paint film. Coatings of this kind are quite inexpensive and in many cases prove less costly than paint alone even in a few years of service.

This paper is concerned specifically with thin metallized coatings of zinc and aluminum on steel and the effects they have on the application, appearance and performance of paints applied over them. It should be pointed out at the outset that these metal coatings are porous, and, unlike galvanized

* Submitted for publication November 7, 1955. A paper presented at a meeting of the Northeast Region, National Association of Corrosion Engineers, Niagara Falls, N. Y., November 2, 1955.

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Abstract

The use on steel of thin metallized coatings of zinc and aluminum is discussed in detail. A number of recommendations are made regarding surface preparation. Consideration is given to the effects sprayed metal coatings have on the application, appearance and performance of the paints applied over them. The cause and remedies for paint failures are discussed with particular attention paid to underground power plant applications. The selection of paints and primers for a given sprayed metal and the use of thinners are discussed briefly.   5.3.2

surfaces, offer an excellent anchor for paint. In spite of the porosity and even when no paint is applied, sprayed zinc and aluminum provide long term protection to steel. This is true for two reasons:

1. These metals are anodic to steel and provide cathodic protection even at small voids in the coating.

2. Sprayed metal coatings become less permeable with time when the conditions of the environment favor the formation of insoluble salts and oxides within the pores. The protective life is, however, related to the thickness, and the thickness to the cost. Where these thin coatings are painted over, the pores are filled and very little, if any, bare metal is exposed direct to the corrosive environment.

Paint Failures

To study the action of sprayed metal under paint, it is first necessary to discuss paint failures, their cause and remedy. This is a broad subject and will be restricted here to the relatively severe corrosive

Figure 1—Outer drive along Lake Michigan in Chicago. The unique retractable traffic lane curbs are made of steel and protected with a coating of .006 inch of zinc. This installation is 14 years old.

Figure 2—Action shot of a Westinghouse capacitor being metallized with zinc as an undercoat for a paint finish. These cases are for outside use on poles and are subject to all weather conditions.
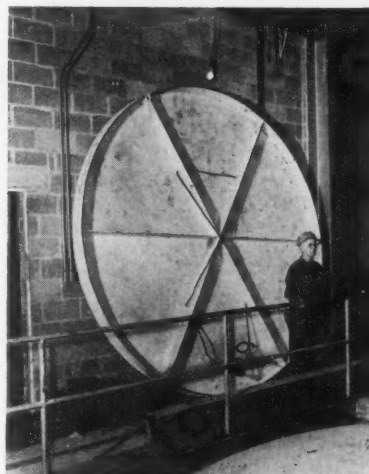

Figure 3—Surge tank floats used by a large midwest utility company. These objects are metallized with aluminum to prevent corrosion and also to prevent contamination of boiler feed water.

conditions existent in power plant applications, and particularly those located underground. This would include applications such as subway transformer tanks, electrical conduit, steam lines, exhaust ducts, etc.

Today a wide variety of very effective paint coating material is available to choose from for severe applications of this kind. This is another reason why more emphasis must be given to paint type coatings. Only a few years ago the only paint protection offered for steel was a drying oil pigmented with red lead or iron oxide. The biggest problem today in selecting paints is the fact that there are so many good ones, with so many different properties, that it is difficult to make the best choice.

Surface Preparation

One of the big steps in the right direction which has resulted from the development of better paints lies in the increased attention being paid to surface preparation. Users have learned that good preparation pays off in long coating life and in more complete protection. The Steel Structures Painting Council has prepared manuals that cover this subject.[1] Moreover, many of the new materials absolutely require more thorough preparation than did the old paints based on drying oils if their real advantages are to be obtained. While there are some manufacturers who still claim that their product can be applied over rust, dirt, oil, or even to wet surfaces, the author has yet to see good performance from such paints in a really severe environment.

In order to evaluate the importance of surface preparation, consideration must be given to the manner in which the paint coatings fail. This, of course, varies widely, depending on the environment and also on the criterion used to determine failure.

Rust Staining

For underground applications the criterion is seldom appearance but there are, of course, many aboveground applications around power plants where appearance is important. For appearance applications the need for preventing rust staining is self-evident. If the protection of steel is the primary requirement,

no repainting ordinarily is done until some rusting appears.

The paint failure which leads to rust may be the result of mechanical damage, crazing or general deterioration of the paint itself, or it may be due to loss of adhesion because of inadequate surface preparation. Paint films are not dimensionally stable; they undergo changes with the passing of time. Shrinkage of the film can lead to crazing or to pulling away of substantial areas. The "alligator" type of failure which develops with contraction of some of the coating materials having low distensibility is a familiar sight. With inelastic coatings the fissures extend through to the steel. Strong adhesion to the base helps prevent this kind of failure. In wet environments almost all paint films pass some moisture by absorption to the base and in such cases rusting of the base occurs even though there is no fissure through the paint film.

Repainting after rusting has begun can be a tricky and unsatisfactory business. The usual practice is to remove the loose paint and rust, spot-prime and then repaint the entire structure. This results in painting

Figure 4—Metallizing operation on SM transformer cases at the Kuhlman Electric Company, Bay City, Michigan. The cases are being sprayed with zinc.
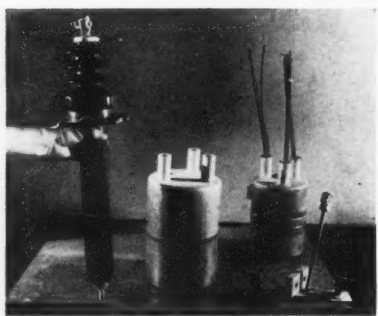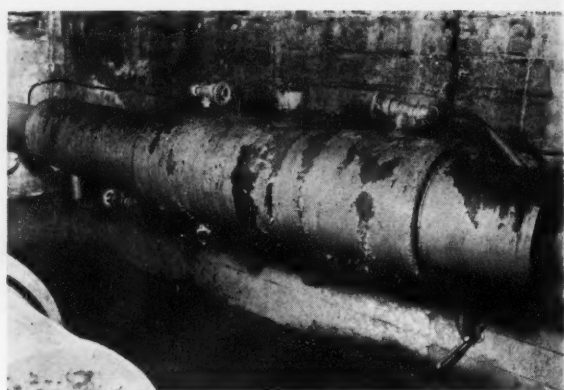
Figure 6—An underground conduit in typical condition between six months to one year after painting. During this period rather severe rusting has occurred under the paint coating.

Figure 5—Same case shown in Figure 4 after assembly with the transformer inside. After welding, the entire exterior surface is sand blasted and then metallized with zinc as a base for a coat of paint. This transformer is used in connection with the "White Way" Street Lighting Systems and is placed inside the metal pole on or near the ground. At the left of the picture is an insulator with a steel stud running through its center. This stud, although cadmium plated, has much of the cadmium burned away during the welding operation. A thin layer of zinc is sprayed on to protect the connector against corrosion.
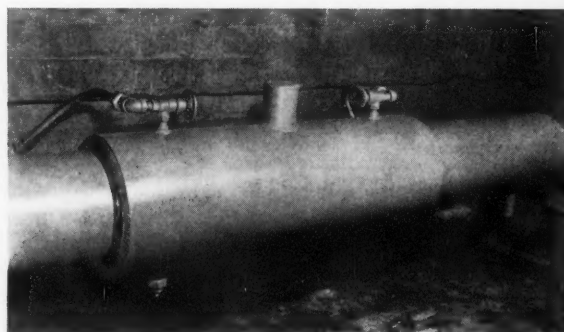
Figure 7—The same conduit pictured in Figure 6 after metallizing with .005 inch of zinc and two coats of aluminum vinyl paint. An inspection two years after this treatment shows no visible change in the coating. Even when the vinyl coat finally fails after about five years, the zinc coating will still be there providing protection and also providing a base for further painting, if desired.

Mill Scale

The easiest surface to prepare is new steel. The most expensive preparation is the cleaning and chipping of badly rusted steel. New steel, however, carries mill scale and mill scale is cathodic to steel and will promote pitting at breaks in the scale as soon as moisture penetrates the paint film. Furthermore, mill scale is stressed in compression and the thicker the film the greater the stress. Mechanical and thermal stresses added to the normal compression stress will cause the scale to break away sooner or later.

It might be added that mill scale provides very little "tooth" to promote paint adhesion. Mill scale can be partially removed by weathering, but can be better removed by flame de-scaling or sand blasting. While rusty steel frequently provides a good initial bond for paints, failures usually result from the fact that not all loose rust is removed, and all absorbed oil, moisture, and dirt not eliminated. Here also about the only satisfactory preparation is sand blasting or flame cleaning plus wire brushing.

Surfaces carrying old paint are usually a difficult preparation problem. While thin brittle paints can be removed by blasting, heavier coats of soft or gummy paints do not yield to any method of attack without

over many areas where the adhesion is gone but where rust has not yet shown through the paint. Needless to say the extra paint hurries the day when the loose sections will fail. Often the original jobs last many years but spot priming and repainting must be done every year or two thereafter.

Even with reasonable diligence and constant maintenance, paint alone seldom provides adequate protection to the steel. For example, bridges and steel structures of all types which are built with the intention of maintaining appearance throughout their life are over-designed with a considerable extra weight allowance. This is an admission that there will be considerable rusting even where regular maintenance is provided.

Where appearance is not important, selection of the most resistant and durable coatings should be made without regard to color, texture, or general appearance. Also, every precaution should be taken to assure that the coating will "stay put." This again brings to mind the subject of surface preparation.

quite a fight. Heating methods, solvents, paint removers and hand scraping are all used and are all very expensive. Flame cleaning can be used, combined with scraping operations, but this often involves a fire hazard and sometimes a health hazard if the paint is pigmented with lead.

It seems to follow that the cheapest method of preparation is the one which can be done the cheapest initially and which requires the least re-doing. This situation can be summed up briefly as follows:

1. Good preparation is costly but it is the cheapest on new steel which has not been painted.

2. After initial serious rusting there is no really inexpensive satisfactory method.

3. The best possible initial preparation will greatly extend the life of the original system.

4. Sand blasting is the surest method of completely eliminating all surface contamination. Where sand blasting can be used it is not necessarily a very costly operation. It costs far less than thorough hand scraping and wire brushing and does a much better job..

Thin Metallizing

This again leads up to metal spraying. With a clean steel surface, metal spraying is an intermediate step which may be considered as part of the preparation. At this stage a thin coat of zinc or aluminum is quite inexpensive. One of the biggest cost factors for a heavy industrial metallizing coating is the grit blast operation required for preparation. Where thin coatings such as 2 to 4 mils are used, particularly for zinc, the requirements of the blast job are considerably reduced. In fact, a first class blast job for paint application is often sufficient and the zinc may be applied without any additional blasting costs. In such cases the benefit derived from the sprayed metal base far outweighs cost in extending the life of the paint coating.

A relatively thin coating of metallized zinc or aluminum provides far stronger adhesion than can be obtained by any other method. Such a coating effectively prevents rusting at the interface, which is the most common cause of paint failure. In the long run the main consideration is maximum protection per dollar. The question now arises, "What is the added cost of the metallized base?" For example assume on a painting job that sand blasting has been specified as the best method of surface preparation. Often a slightly better job may be required for metallizing, so 1¢ to 3¢ per sq ft should be added for more thorough blasting. The cost of the metal, assuming a thickness of 3 mils of zinc, will be about 6¢ per sq ft. The spraying cost including labor and gases will be about 3¢ per sq ft since one man can cover 180 to 360 sq ft per hour depending on the job and gun used. If aluminum is used instead of zinc the cost will be slightly lower for spraying because of the

light weight of aluminum. At the same time a slightly better blast job may be required so the total cost would be calculated at about the same as zinc.

Summing up these figures, it is found that 10¢ or 12¢ per sq ft has been added to the cost of the job. Some of the advantages gained from this expenditure can be seen from the following paragraphs.

Discussion

Consider an electrical conduit or perhaps a transformer case in an underground chamber. Even the best paint systems have a relatively short life and rust streaks appear within a few weeks or months after painting. Continual touch-up is the usual thing unless sprayed metal is used beneath the paint. Not only will sprayed zinc or aluminum greatly extend the life between repainting, but it greatly reduces the problem at the time of repainting (a point which bears considerable emphasis.) With no rust beneath the coating and no loose paint, all that is required to prepare for repainting is to hose down the surface and allow it to dry.

Figures 1-7 show some of the ways in which metallized coatings can be used. One class of application that bears special emphasis is steam lines, exhaust ducts and other hot metal surfaces. Here a thin coating of sprayed aluminum, followed by aluminum pigmented silicone paint solves the problem that literally has no other satisfactory solution. Silicone paints withstand heat and provide excellent appearance but give serious adhesion problems in many environments unless bonded by sprayed aluminum.

A short discussion seems in order concerning areas which are not readily accessible since there are many situations of this kind in underground installations. Non-accessible areas can be very expensive indeed. Even the proper inspection of such areas can be very expensive, particularly if dismantling, rigging or removing to another site must be done to inspect or repaint. In such cases the cost can greatly exceed preparation and cleaning costs. Underground transformer cases are a good example of this.

Another problem that arises in this connection, particularly around power plants, is that it is not always possible to shut down the various facilities to allow for the maintenance work. In steam plants applications of this kind can be found almost endlessly — piping, ducts, coal bunkers, conveyors, stacks, etc. In hydro stations there are draft tubes and turbine housings which collect condensate continuously.

A few words should be said here about the limitations of paint systems used over sprayed zinc and aluminum. Paints and primers used must be compatible with the sprayed metal, and some materials compounded for steel or galvanized zinc are not satisfactory over a metallized base. In particular, sprayed zinc should never be confused with galvanized zinc. On galvanized surfaces strong acid primers sometimes are used which actually attack the galvanized surface and etch it. Sprayed zinc on the other hand offers a natural bond for paint; primers should be used not to etch the coating, but as in-

hibitors. For instance, wash coat primers containing phosphoric acid are frequently recommended on sprayed zinc for inhibitive purposes, but the acid content must not exceed 4 percent. Some primers for galvanized surfaces have acid contents up to about 16 percent and these would be death to sprayed metal.

When painting over sprayed metal for use in damp environments it is generally advisable to apply an inhibitive primer before applying the regular pigmented paint, particularly where heavy impervious paint coatings are used. The primer prevents the generation of gas on the freshly sprayed zinc or aluminum coating, which might result in blistering of the paint. Most of the paints used on structural steel are compatible with sprayed aluminum. In the case of sprayed zinc, however, there are a number of paints which should not be used. Metallizing contractors and equipment manufacturers are in a position to specify the best type for each job. The question of whether zinc or aluminum is the best metal for the job is also one which will depend upon local conditions. This question also should be the subject of recommendations of the contractor or manufacturer.

When applying paints direct to sprayed metal it frequently is advisable to thin down the first one or two coats so as to obtain better penetration into the base. At least one large metallizing contractor advises applying one coat or two with the same paint unpigmented and thinned down. For the best job the base coat is unpigmented and diluted with three parts of thinner to one part of paint, and the second coat unpigmented and diluted one part of thinner to one part of paint. This is followed by full strength pigmented material in the desired number of coats. The thinned paint vehicle, however, is not a substitute for inhibitive primer which as mentioned before should always be used where the job is subject to severe moisture conditions.

Conclusion

The author feels that if the right metal is chosen and the right paint properly applied over it, there will be a great many applications where the best long term economy and the most complete protection can

be obtained where sprayed metal is used as a base for paints.

Reference

1. Joseph Bigos (Editor). Steel Structures Painting Manual. Steel Structures Painting Council, Pittsburgh, Pa. Vol. I (Good Painting Practice), 1954; Vol. II (Systems and Specifications, 1955)

DISCUSSION

Question by E. H. Caldwell, Oldbury Electrochemical Company, Niagara Falls, New York:

What experience has your company had with sprayed aluminum paint on air washer equipment in chemical fume atmosphere?

Reply by H. S. Ingham:

None. Below pH 3.5 aluminum coated with a vinyl system is known to fail. We would have to depend on a trial application for making recommendations.

Questions by V. J. Payton, Commonwealth Edison Company, Chicago, Illinois:

1. Is carbon steel flashing advisable for thin metal coatings that are to be painted?
2. Is there a paint or sealer other than silicone aluminum for condensate storage tank service at 170 F?

Replies by H. S. Ingham:

1. No. Carbon steel flashing is of very little advantage for thin metal coatings but gives a much stronger bond for thick coatings. Steel flashing ordinarily is not recommended below .008 inch aluminum and .010 inch zinc thicknesses. These coatings when painted are usually .003 inch to .006 inch thick.

2. Yes. A number of condensate storage tanks have been done successfully for use at elevated temperatures with phenolic sealers manufactured by United Chromium Corp. However there have been some failures with this phenolic. Subsequent information indicates that the best sealers for this use can be obtained from Wisconsin Protective Coatings, Green Bay, Wisconsin. These are catalyzed phenolics and epon resins and are known as "Plasite."

Any discussions of this article not published above will appear in the June, 1957 issue.

A Case History in Cooling Water Treatment*

By C. J. HOLLAND, JR. and W. A. TANZOLA

Introduction

IN THE PAST few years corrosion, wood deterioration, and water-borne solids have been recognized as being among the primary problems of the open-type recirculatory water cooling systems. By design, the waters of these systems have warm temperatures, high oxygen concentration, and heavy salt content. They serve as an ideal environment for corrosion while functioning as a heat removal medium. There are of course compensating properties in some waters, such as scaling tendency and adverse pH, which act to contain the corrosion. On the other side of the ledger is a growing list of water properties which have been tagged as accelerators of corrosion attack.

The case history considered in this paper describes the deleterious action of water-borne wood fibers and of circulating corrosion products, and traces the effect of the treatment introduced to control the corrosion and to eliminate the wood deterioration of the cooling tower.

The Plant and Water System

The water system under consideration is part of the Delhi Natural Gasoline Plant located in northeastern Louisiana and operated by the Sun Oil Company. This plant processes casinghead gas and gas well gas to meet transmission line specifications and fractionates the recovered liquefiable hydrocarbons into commercial products. Principal operational units of the plant are five 1000 horsepower compressors, an absorber operating at 500 psig, a reabsorber, two distillation columns, conventional fractionating towers, three Wickes 160 horsepower water tube boilers, gas dehydrators, and a 200-ton refrigeration unit.

Heat evolved from the various unit processes is removed by a typical water cooling system in which the water circulates at the rate of 4500 gallons per minute from an induced draft redwood cooling tower through shell and tube heat exchangers located in the plant operational area. From there the water goes back into the tower. The tower itself is composed of five induced draft sections, each designed for cooling a maximum water load of 1050 gallons per minute from 110 F to 85 F with an 80 F wet-bulb atmospheric condition. Ample make-up water for the cooling system, boilers, and plant utilities is furnished by two water wells completed in a 370 foot sand. Each well is capable of supplying 310 gallons per minute of a clear, soft water as shown by the analyses of Table 1.

CHARLES J. HOLLAND, JR. is Senior Gas Engineer with the Sun Oil Company, Dallas, Texas. He joined the Natural Gas Department, Dallas Division of Sun Oil Company in 1948 shortly after receiving a BS in chemical engineering from The Rice Institute. From 1950 through 1955 he served as the water treating engineer for the division gasoline plants. At the present time he is engaged in economic evaluation for the department. Mr. Holland is a member of NACE and American Institute of Chemical Engineers.

WILLIAM A. TANZOLA has been with W. H. & L. D. Betz, Philadelphia, Pennsylvania, for 18 years where he currently serves as Director of the Engineering Department. He holds a BS in chemical engineering from Drexel Institute of Technology and is the author of numerous papers on various phases of industrial water conditioning. Mr. Tanzola is a member of NACE and is on the Water Committee of TAPPI.

Abstract

The problems of corrosion and tower wood deterioration are commonly encountered in recirculation cooling water systems. At the Delhi Natural Gasolina Plant in Louisiana the concurrent presence of these two problems resulted in plugging of heat exchanger tubes and in high metal loss throughout the system. The corrosive potential of the water was aggravated by "fiber throw" in the water caused by serious deterioration of the tower wood. The "fiber throw" enmeshed with corrosion products created cell action which produced serious pitting and tuberculation.

A program of treating the water was undertaken both to minimize the attack of the wood and to prevent corrosion. Effectiveness of the treating program was followed by corrosion studies to evaluate the benefits of each step taken. Initially, rather high treatment concentrations were necessary to keep corrosion under control. But as the clean-up program to aid in freeing the system of corrosion products and fiber took effect, the corrosion load was reduced, which permitted good control of corrosion with normal treatment concentrations.   4.6.4

Early Treatment History

The plant began operation in May, 1948. Because a plentiful supply of unusually low hardness natural water was available, the cooling water treatment for the first year and a half consisted of controlling the cycles of concentration to approximately three, and maintaining a chlorine residual of .75 ppm in the
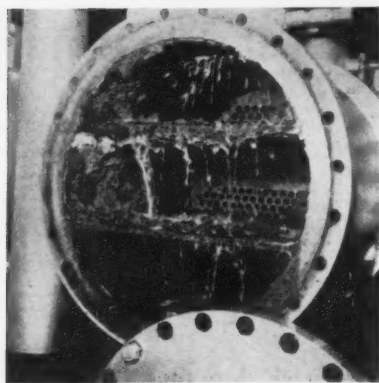
Figure 1—Corrosion products found in heat exchanger.
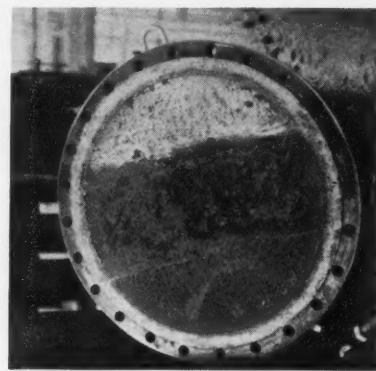

Figure 2—Corrosion products in heat exchanger.

TABLE 1—Characteristics of Well Water and Tower Water

	Well No. 1	Well No. 2	Tower Basin
Total Hardness as CaCO₃........	6 ppm	8 ppm	16 ppm
Calcium as CaCO₃...............	4 ppm	6 ppm	10 ppm
Magnesium as CaCO₃............	2 ppm	2 ppm	6 ppm
Alkalinity to P as CaCO₃........	20 ppm	10 ppm	200 ppm
Alkalinity to M as CaCO₃........	466 ppm	432 ppm	1350 ppm
Sulfate as SO₄..................	12 ppm	12 ppm	36 ppm
Chloride as Cl..................	350 ppm	580 ppm	1400 ppm
pH Value......................	8.65	8.4	8.8-9.4

circulating water. Under these conditions the pH of the water ranged between 8.8 and 9.4.

Early in 1949, inspection of the depropanizer column reflux cooler and debutanizer reflux cooler disclosed that iron oxide deposits were collecting in the heat exchanger heads where low water velocity existed. At this time it also was becoming increasingly evident that the cooling tower wood was deteriorating. There was a build-up of matted wood fibers on the filter screens of the cooling tower pump pit. Lath samples removed from the cooling tower at points of full water fall had a heavily eroded appearance. Further inspections were made in the latter part of 1949 and early 1950 which showed corrosion products to be accumulating on the baffles and channel box sides of the heat exchangers in the form of ½ inch to 1½ inches sharp, needle-like deposits (Figures 1 and 2). Beneath these tubercles were pits and large areas of active corrosion. Upon examination, it was discovered that these deposits were often breaking off from their areas of formation, migrating through the system and, finally, either adhering to tube sheets or plugging the tubes.

From these experiences in the first two years of operation, it was concluded that additional treatment of the cooling water system would be necessary to prevent further deterioration of the cooling water tower wood and to control corrosion. Both the fiber throw and formation of corrosion products had progressed at a serious rate and were causing fouling of the tubes and interference with heat transfer. A high zinc content was found in the deposits analyses, indicating that some attack of the admiralty tubes also was being experienced.

Recommendations

Upon the request of the plant operators, a firm of consultants in water treating problems was requested to submit recommendations for treatment of the cooling tower water. Upon examination they diagnosed the wood deterioration as a chemical attack brought about by the high alkalinity. For its alleviation they proposed mineral acid feed to maintain the pH of the circulating water in the range of 7.1 to 7.4. For corrosion control they recommended the "Dianodic Method" of treatment. The "Dianodic Method," which has been described thoroughly elsewhere in the literature,[1, 2, 3] employs two anodic inhibitors—phosphate and chromate—in controlled ratio and under controlled pH conditions to eliminate the pitting tendencies encountered with the separate use of either phosphate or chromate alone. Control of cycles of concentration between 3.5 and 4.0 were recommended together with a continuation of chlorination for slime control.

Acid Handling Facilities

The use of acid was not altogether new at this plant, but up to this period only small quantities of acid had been used in drum lots for boiler water treatment. It was felt that in the quantities now required acid could be handled more safely and more economically in bulk volume. Consequently, facilities were installed for handling the concentrated sulfuric acid. The equipment consisted essentially of a bulk acid storage tank feeding by gravity through 1400 feet of 2 inch standard weight steel pipe to the 80-gallon tank for boiler feed-water treatment and to the 60-gallon "day" tank for cooling tower water treatment. For the bulk acid storage, an unlined steel 12,000 gallon tank was mounted on eight-foot stanchions near the railroad loading rack to facilitate unloading the acid tank cars. From the "day tank" at the cooling tower, the acid flows by gravity to the tower basin where, as it enters, it mixes with a side stream of water over a ripple trough.

Exclusion of water vapor from all three tanks is accomplished by permitting the tanks to breathe to the atmosphere through a container of dessicant, which is replaced periodically. After five years of use, there has been no evidence of internal corrosion in this steel acid-feed system. As a safety measure, valving on the original acid piping was arranged so

that no tanks or pipe section could be closed in to permit pressure build up. Later, however, in order to allow occasional inspection and cleaning of the "day" tanks, an additional valve was installed to close off the tanks from the system. Provision was made, however, for locking the valve in the open position during acid feeding operation. In the event of acid spillage or other accident, instant-action, spray-type showers are available at the storage tanks, loading areas, and treating points.

Analysis of Treatment Proposal

It was recognized that to be completely effective, the proposed treatment had to overcome the natural corrosive potential of the circulating water as well as to control the deleterious side-effects resulting from the sloughing off of two years of heavy accumulations of corrosion products and wood fiber. For heavily corroded systems of this order, it was expected that the length of the sloughing off period might be appreciable. However, since the corrosion products in this case had been formed in an elevated pH environment (i.e., pH 8.8 to 9.4), the lowering of the pH would assist the penetrating action of the polyphosphate in the dislodging and the break-up of the undesirable material.

This dislodgment of the corrosion product accumulations presents a number of problems in itself. For one, instead of being carried out of the system in the blow-down stream, the water-borne material may tend to settle out at points of slow circulation. These reformed deposits have properties of density and porosity favorable to the establishment of electrolytic cell type corrosion. The very same properties make it difficult or impossible for treatment to penetrate to the metal and stifle the attack. (Figure 3 shows a floating head from an exchanger in another plant, from which corrosion product accumulation more than 1 inch in thickness had been removed to show the serious pitting and etching which had occurred underneath.)

A second problem is created when the tubercles break off from their areas of original formation and lodge in the tubes of the heat exchangers. If the circulating water has any scaling tendency, partial blockage may soon become complete due to scale formation around the restricting nodule. This is brought about by the elevated skin temperature of the tube surface at this point due to inadequate water flow. (An extreme case is shown by Figure 4, picturing an exchanger tube taken from another plant. In this instance, examination of the tube disclosed that a nodule had entered and lodged part way in the tube. The dark layers show the initial scale formation that took place, which was primarily calcium sulfate and magnesium silicate. The core of the deposit consists primarily of sodium sulfate and sodium chloride.) The effect of such blockages on the cooling efficiency of the exchanger is obvious.

In addition to the problems caused by migration and redeposition, the sloughing off of old corrosion products in the early stages of treatment exposes small areas of clean metal surface which become anodic to the adjacent corroded areas, thus promot-
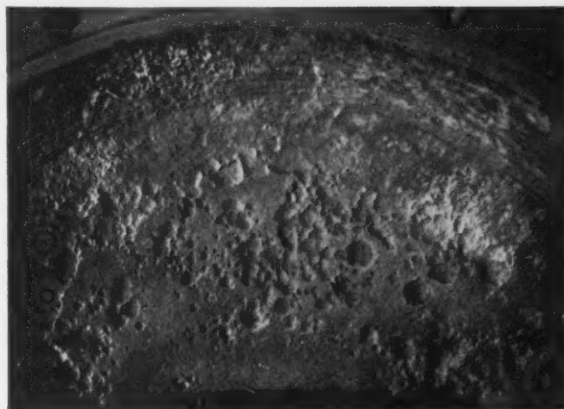
Figure 3—Floating head from an exchanger. A corrosion product accumulation more than one inch in thickness was removed to show the serious pitting and etching which had occurred underneath.
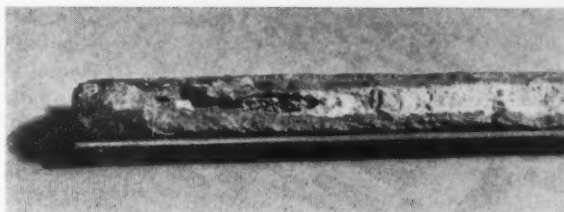
Figure 4—Scale formation in an exchanger tube.

ing more cell type corrosion of the insidious pitting variety.

Treating and Testing Program

The recommended treatment was inaugurated in November, 1950, after the completion of the acid handling facilities. Initial control test limits were provided to maintain 70 ppm of a mixture of chromates and polyphosphates in the circulating water.

During the early stages of treatment, the pH, cycles of concentration, and ratio of chromate-to-phosphate were adjusted as required to compensate for the sloughing off of old corrosion products. After the system had been cleaned, further tests indicated an optimum treatment level to be between 40 and 60 ppm with a weight-ratio of two parts PO_4 to one part CrO_4. Reversion rate is indicated by water analyses which show two parts "total" phosphate to one part of "ortho" phosphate.

A coupon test program was instigated at the time of the new treatment. It was not feasible to test all the large variety of water conditions in such a system, so one by-pass line and coupon holder was constructed on the main return water header line to the cooling tower, and another on the main cold water line leaving the tower. The average hot water temperature was 110 F, and the cold water temperature was 85 F. Coupons used were polished $\frac{1}{2}$ inch x 3 inch strips of 18 gauge, cold rolled, SAE 1010 steel. During each test period a series of four coupons were installed in each by-pass arrangement. Coupons were then removed one at a time during the test period in

order to provide coupons with increasing times of exposure. Corrosion attack was reported as total metal loss in milligrams and also as a rate of average penetration in mils per year.

Initial Test Results

The initial tests shown in Table 2 graphically portray the accelerated corrosion caused by the re-deposition of migrating corrosion products and other debris from the water. Deposits on these coupons were found to be algea, corrosion products and wood fibers. Under the deposits severe etching and pitting had occurred giving erratic metal loss figures ranging from 12 to 28 mils per year. The treatment level for this test period had been 70 ppm, which on laboratory test waters of the same chemical analysis had reduced corrosion weight loss to one-to-two mils per year.

In order to halt the cumulative effect of the migrating particles and the attending cell-type corrosion, the treatment level was raised to 200 ppm with the result that the losses dropped to an acceptable 2.2 mils per year (Table 2). Continued treatment at this level for an extended period would have maintained the desired protection while the existing corrosion product was being dislodged and discharged from the system in the blowdown. However, the high costs of the treatment in this instance suggested that additional effort be made to clean up the system.

To demonstrate the importance of a clean-up program, and to show what portion of the corrosion load was due to the water borne solids in the circulating system, a home-made filter was constructed and installed immediately ahead of the specimen test rack handling the hot return water to the tower. For comparison purposes, coupons were also installed in unfiltered water leaving the tower. Unfiltered water was tested to contain between one and fourteen pounds of suspended solids per 100,000 gallons circulated. Treatment levels were reduced to 100 ppm for this test period. From results of this comparison given in Table 3, it will be noted that the corrosion rate in the cold, unfiltered water continued to be varied and was on the order of 8.5 mils per year, while coupons in the hot, filtered water lost only 1.3 mils per year. The higher rate and the erratic individual coupon results show that the effect of migrating corrosion products and fiber throw is quite pronounced. The reduction experienced on the coupons in the filtered water was actually greater than indicated here, since the earlier tests made before the filter was installed (Table 2) had shown the 110 F

return water to be more corrosive than the cold water.

Clean-Up Program

Evidence from the above tests having established the importance of clean water, a clean-up program was initiated to: (1) free the heat exchangers of corrosion products, and (2) remove as much as possible of these products and wood fiber throw from the circulating water.

At every opportunity the various exchangers were opened and cleaned. Also, consideration was given to the installation of a side-stream filter on the circulating water header to aid in removing the sloughed off materials, and particularly, to eliminate fibers. At this time, however, it was felt that once the system was clean, treatment and blowdown would take care of the normal incidence of foreign matter. Accordingly, instead of purchasing the possibly more effective side-stream filter, it was decided to install fine-mesh screens over the more coarse screens located in the tower pump pit. These screens have been very successful in reducing the fiber content of the water; however, they require surveillance on the part of plant personnel to prevent excess build-up of "filter cake", resulting in rupture of the screens or loss of suction by the circulating pumps.

During the initial period of use it was necessary to remove the screens every hour or so. In time, the frequency of screen cleaning decreased to a week between removals. Figure 5 shows a typical mat of debris collected on the screens. This photograph was taken at the stage of the clean-up program when the debris collected proved to be composed mostly of wood fibers.

Cooling Tower Wood Deterioration

As has been mentioned earlier, the eroded appearance of the wood and the presence of wood fibers in the water had shown that the cooling tower wood was deteriorating. As the effects of treatment and the clean-up program became apparent by the decline in the amount of circulating corrosion products, it was noted that the fiber concentration did not at first show a similar decline. After system blow-downs, tower washings, and screening, the fiber content would return to a concentration range of 1 to 8 pounds of wood per 100,000 gallons. This suggested that the fiber formation was continuing in spite of the alkalinity control then in operation. The question therefore was raised as to whether or not some additional factor might have been responsible other than

TABLE 2—Corrosion Results of Initial Study

Days Exposed	Treatment Level (ppm)	Type of Water and Temperature	Loss, mgs.	Penetration, mpy
30	70	Pump Discharge—85 F	576	18.2
60	70	Pump Discharge—85 F	1451	23.0
90	70	Pump Discharge—85 F	1310	13.8
112	70	Pump Discharge—85 F	1450	12.4
30	70	Return Line—110 F	738	23.2
60	70	Return Line—110 F	1770	28.0
90	70	Return Line—110 F	1488	15.7
112	70	Return Line—110 F	2151	18.2
28	200	Return Line—110 F	73	2.5
56	200	Return Line—110 F	131	2.2

TABLE 3—Effect of Suspended Matter

Days Exposed	Type of Water and Temperature	Loss, mgs.	Penetration, mpy
14	Pump Discharge (Unfiltered)—85 F	51	3.5
28	Pump Discharge (Unfiltered)—85 F	221	7.5
42	Pump Discharge (Unfiltered)—85 F	205	4.6
56	Pump Discharge (Unfiltered)—85 F	509	8.6
14	Return Line (Filtered)—110 F	78	5.3
28	Return Line (Filtered)—110 F	137	4.6
42	Return Line (Filtered)—110 F	58	1.3
56	Return Line (Filtered)—110 F	76	1.3

Note: Treatment level was 100 ppm.
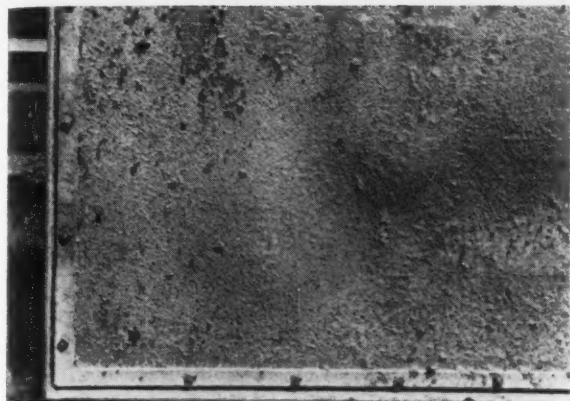
Figure 5—A typical mat of debris collected on screens.

TABLE 4—Results After Clean-up Program

Days Exposed	Loss, mgs.	Penetration, mpy
14	24	1.6
28	50	1.7
42	62	1.4
56	41	0.7

Note: Treatment level was 40-60 ppm; pump discharge was 85 F water.

TABLE 5—Chemical and Acid Cost

Period	Chemical and Acid Cost/Day	Chemical and Acid Cost/1,000,000 Gallons Circulated
Start of new treatment	$10.95	$1.69
First increase, fair protection	$15.41	$2.38
Experiment with 200 ppm	$31.31	$4.82
Experiment with 100 ppm with filter on coupon test rack	$17.35	$2.68
Good protection—after clean-up program	$ 8.72	$1.34

Figure 6—Sample of wood from five year old tower (left) and seven year old tower (right).
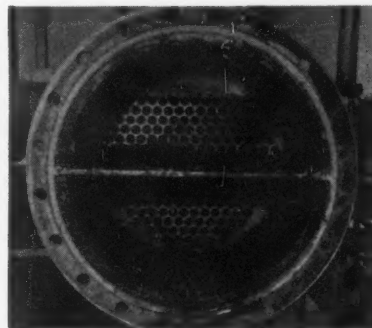
Figure 7—A heat exchanger six months after cleaning.

chemical deterioration of the tower wood resulting from the high alkalinity maintained during the first two years of plant operation.

The plant personnel, suspecting the possibility of fungi attack, thoroughly inspected the cooling tower for evidence of rot or decay. A few isolated brown spots were noted on the surface of some of the wood fill, but this appeared to be a surface condition only, since no viable wood-destroying fungi were found in the culture tests made. Additional culture tests, wood analyses, and water analyses were made, but no other cause for the wood deterioration was found other than that originally noted (i.e., chemical attack). Since chlorine concentration below 1 ppm has not been known to be harmful under these conditions, it appeared that the two years of the high alkalinity water was responsible for the wood failure.

While some wood loss evidently is continuing, no thinning of the lath or grooving has been experienced in the past five years of treatment comparable to that which occurred in the first six to twelve months of plant operation. It might be pointed out also that a fifth cell was added to the existing cooling tower six months after the starting of the recommended acid treatment; after five years of operation there was no significant deterioration of the wood. Figure 6 shows a sample of the wood fill taken from

the fifth cell as compared with a similar piece from the original portion of the tower—the former is five years old, while the latter is seven years old.

Treatment Results

The clean-up program successfully reduced the amount of circulating debris to a point where it was no longer a significant factor in the corrosion load. Following tests made at decreasing levels of treatment, an optimum range of 40 to 60 ppm was established for treatment control points. The success of the treatment and clean-up programs could be seen in the condition of the equipment and in the results of later coupon tests.

Figure 7 pictures the condition of a heat exchanger about six months after cleaning, showing that corrosion and serious redeposition of migrating corrosion products had been brought under control. Table 4 shows data from coupons exposed to the lower treatment levels in which the penetration rate is reduced to one mil per year and less. Comparison of these results with those initial coupon studies of Table 2 again show the additive effect that water-borne foreign matter has upon the normal corrosiveness of the

water. The chemical composition of the water in both studies was essentially the same.

"Dirty" water may or may not present a readily apparent maintenance expense; however, the cost of the additional treatment chemicals required by the suspended solids is more easily recognizable. At the Delhi Plant, beginning with the first of treatment in 1950, the chemical and acid costs per 1,000,000 gallons of water circulated ranged from $1.69 through $4.82 during the experiment with heavy chemical dosage, to $1.34 for treatment after the clean-up program had significantly reduced the quantity of water-borne solids. With a satisfactory level of protection being obtained by both the 200 ppm treatment and the optimum treatment of 40 to 60 ppm, a value of $3.50 per 1,000,000 gallons circulated may be placed on the additional corrosion load created by the wood fibers and the sloughing of corrosion products (see Table 5).

Case for Corrosion Treatment

The treatment of cooling water for control of scale formation has been an accepted practice for many years. However, the treatment of cooling water to minimize cooling tower wood deterioration and for corrosion control has not been practiced widely. This slower acceptance of making provision for good corrosion control may have been based on the thought that effective treatment for this purpose is prohibitively expensive, which may have been justified in the past when high concentrations of corrosion inhibitors were recommended. However, with the development of newer corrosion control methods, such as the "Dianodic Method" used at the Delhi Plant, the cost of corrosion control has been reduced to a range that is economically attractive. As in this instance, automatic elimination of high alkalinity chem-

ical attack of cooling tower wood is secured with corrosion control methods functioning in a pH range of 6.0 and 7.5.

The case history secured at the Delhi Plant discloses the importance of good engineering and sound chemical study and evaluation for an economical and effective corrosion treatment program. The benefits derived by the Delhi Plant have been the assurance of good heat transfer, the minimizing of cleaning and maintenance, and the avoidance of expensive equipment replacement.

References

1. H. L. Kahler and C. George. *Corrosion*, **6**, 331-340, (1950) Oct.
2. H. L. Kahler and C. George. Proc. 11th Ann. Water Conf. Eng. Soc. of W. Pa., 1-18, (1950).
3. H. L. Kahler and P. G. Gaughan. *Ind. Eng. Chem.*, **44**, 1770-1774, (1952) Aug.

DISCUSSION

Comments by C. P. Dillon, Carbide and Carbon Chemicals Corp., Union Carbide and Carbon Corp., Texas City, Texas:

Although Mr. Holland found that he could more readily inhibit water which had been filtered free of wood deterioration products and other foreign matter, our experience with this inhibitor has been that clarification of make-up water for the elimination of mud and silt did not improve the performance of the inhibitor. In fact, we found it somewhat more difficult to achieve protection in filtered than in unfiltered water. I would like to state also that while this treatment apparently is very successful there is, in our Brazos River water at least, some continued deposition, probably of complex phosphates, on our heat exchanger tubes. We find the chromate polyphosphate inhibitor not entirely compatible with good heat transfer.

Any discussions of this article not published above will appear in the June, 1957 issue.

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A Special N-80 Steel Tubing Developed in France
To Resist Sulfide Stress Corrosion in Sour Gas Wells*

By L. CAUCHOIS, J. DIDIER and E. HERZOG

Introduction

THE PRESENCE of hydrogen sulfide in wells may bring about a number of critical problems in oil and natural gas production. This is particularly true when the wells are deep and under high pressure. The difficulties encountered result from the hydrogen sulfide corrosive action which acts on steel in various ways.

In the United States the National Association of Corrosion Engineers has a number of Technical Committees which are vitally interested in these problems. These committees include T-1G (Sulfide Stress Corrosion Cracking), T-1D (Sour Oil Well Corrosion), and T-1B (Condensate Well Corrosion.) A number of interesting papers also have been published on this subject.[1]

In France the problem of sour gas production under particularly severe conditions was raised for the first time in 1951 with the discovery of the Lacq gas field. The field is a deep one (11,400 to 13,000 feet). The surface pressure reaches 7,538 psi with closed-in wellhead and the temperature at the bottom is about 284 F. The gas contains 15 percent H_2S and 6 percent CO_2, with the balance consisting mostly of methane. It is possible that the conditions at Lacq may be even more severe than those found in American sour gas fields.

The first well in the Lacq field to be attacked by hydrogen sulfide was well No. 3. When the gas formation was entered an uncontrolled blowout occurred due to the failure of a drill pipe string under the action of hydrogen sulfide. The 6⅝ and 9⅝-inch casing failed successively and 30 tool-joints were found parted in the well. Figure 1 shows a 3½-inch tool-joint which was broken at Lacq No. 3 after 48 hours' exposure to the gas.* The broken tool joint shows the two types of cracks observed on the various tool joints seen on the spot:

1. Transversal cracking originating in stress concentration areas (change of section, recesses, thread roots, and holes).

2. Longitudinal cracking due to the hoop stress in the tool joint on the drill pipe. The appearance of the failure is brittle without plastic deformation. Externally, there was no sign of corrosion.

In addition to the main cracks, there were other

Abstract

The presence of hydrogen sulfide in the Lacq gas field in France resulted in a number of equipment failures. It was found advisable to use a steel tubing having the N-80 grade steel mechanical properties but having a better sulfide stress corrosion resistance under the action of hydrogen sulfide than the conventional N-80 steel. The steel developed for this purpose was designated APS 10 M4 and was a chromium-aluminum-molybdenum alloy which had been heat treated in such a manner as to obtain a thermodynamically stable structure of carbon-free ferrite with highly dispersed fine carbides.

Specimens of the newly developed steel were subjected to a number of laboratory tests including the Jones Test, Cantilever Beam Test, U-Bend Test, Expansion Test, and Tensile Test. Extensive data are given from these tests. It was found that appropriately heat treated APS 10 M4 steel had a very high resistance to hydrogen sulfide as compared with other materials in general and with the conventional N-80 steel in particular.

Field tests were made on 2⅜-inch tubing made from APS 10 M4 steel. After six months of testing it was found that the steel was sufficiently resistant to hydrogen sulfide to be satisfactory for use at the Lacq field.   **3.2.2**

small cracks starting particularly at the thread roots. The cracks were intergranular and transgranular.

The drill pipe lengths of the same string, exposed to the same conditions but not submitted to the same stresses, already showed incipient cracks.

A number of problems are involved in the use of N-80 tubing in sour wells. The higher the mechanical properties of the material, the greater is its susceptibility to atomic hydrogen embrittlement. Up until now N-80 tubing has been considered a weak link in deep and high pressure well production because of its susceptibility to failure even with inhibitors and coatings. This is a serious matter inasmuch as tubing failure in some cases can result in the loss of the well or even the field.

As a consequence of the failure at Lacq, the Societe Nationale des Pétroles d'Aquitaine requested various laboratories to give their opinions about the causes of these accidents. The Research Centre for Physics of Metals, headed by Professor Paul Bastien at the Ecole Centrale des Arts et Manufactures in Paris, concluded that the problem was a steel embrittlement phenomenon by atomic hydrogen evolved during the corrosion of iron under the action of gaseous hydrogen sulfide.**[2,3,4] This embrittlement was then experimentally reproduced.

In 1951, Bastien and Azou established the theoretical basis of the mechanism of hydrogen embrit-

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* For further details see Compte-Rendu du Congres 1952 de l'Association Francaise des Techniciens du Petrole, Paper No. 3 on Lacq No. 3 by Cauchois.

** Studies cited in Reference 2 showed that if sulfide of the Na_2S type is present there is increased danger of hydrogen embrittlement. This must be the case in Lacq.

L. CAUCHOIS is technical adviser to the general management of Societe Nationale des Petroles d'Aquitaine, Paris, France. After receiving an engineering education at Ecole Centrale, Paris, and Ecole du Petrole, he joined Petrofina subsidiary in Rumania as drilling and production engineer. In 1940 he was transferred to Turkey where he served as petroleum adviser to the Turkish government. In 1941 he returned to France to join RAP in St. Gaudens as head of natural gas production; 5 years later he became technical manager of SNPA in Pau. Mr. Cauchois has done extensive work in connection with gas field development and corrosion problems at the Lacq field.

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E. HERZOG is manager of the Research Department, Pompey Steelworks, Nancy, France. In 1932 he wrote his doctoral thesis (Lille University) on the subject of differential aeration cells, inhibitors, and sea water corrosion of Al-Mg alloys and low alloyed steels. From 1927 to 1933 he was a scientific coworker of Prof. Chaudron's at French Air Dept. Dr. Herzog has done work in the field of high-strength weldable steels and steels for metallic tires and cartridge cases. He received the 1956 H. Moissan medal for work relating to steels resistant to stress corrosion cracking in nitrates and hydrogen sulfide.
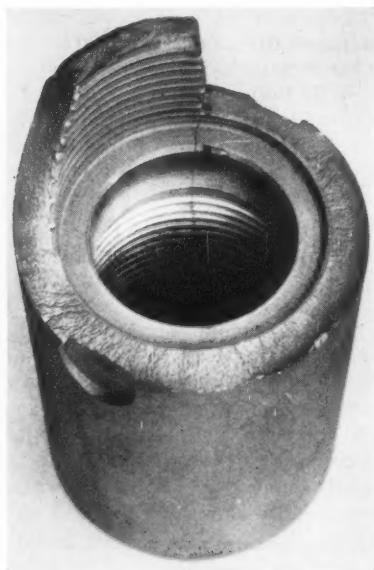
Figure 1—A 3½-inch tool joint broken at Lacq No. 3 after 48 hours' exposure in sour gas.
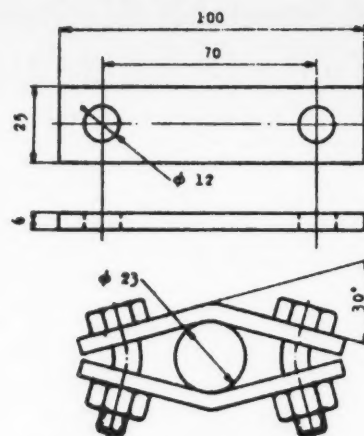
Figure 2—Jones Test. All dimensions are given in millimeters.

tlement and showed the part played by the proton atmosphere around the dislocations and lattice imperfections of iron and steel.[5,6,7,8] It was found that the embrittling effect of hydrogen will be equally minimized in a thermodynamically stable material or alloy where the dislocations and lattice imperfections are minimized.

This conclusion has been verified in two different ways. In 1951 Hobson and Sykes published experimental data showing the advantages of steel having a spheroidized structure.[9] Then in 1954 Bastien and Amiot published the results of an experimental study on the susceptibility to hydrogen of any alpha structure (both spheroidized and unspheroidized).[10]

The hydrogen action explanation for the Lacq failure was taken under consideration by SNPA instead of other suggested mechanisms (intergranular corrosion with intergranular sulfide precipitations, vibration, failure, etc.) The company then asked the Research Center of the Ecole Centrale to classify by the above named processes the French and foreign N-80 steels recommended to resist hydrogen sulfide corrosion.

SNPA played an important role in helping the steel-producing companies in the development of highly spheroidized micrographic structures. In addition, Societe des Aciéries de Pompey and Centre d'Etudes Vallourec undertook independent laboratory studies in 1951 at the request of American oil companies. The failure of Lacq No. 3 served to accelerate the investigations undertaken by the latter two laboratories.

In 1953, E. Herzog made application for a patent covering a special steel having excellent stress corrosion resisting properties to hydrogen sulfide action. This was made possible because of work done in collaboration with Professor A. Portevin on stress corrosion cracking of low alloyed steels in nitrates.

The steel mentioned above became known as APS 10 M4, having been derived from APS 10 M which is used successfully where resistance to intergranular corrosion through the action of nitrates is required. The new steel can be described as a chromium-aluminum-molybdenum alloy, heat treated in
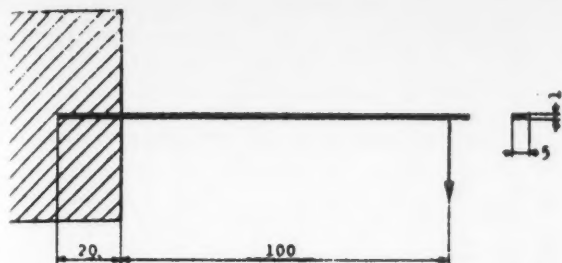
Figure 3—Cantilever Beam Test. All dimensions are given in millimeters.

Figure 4—U-Bend Test. Dimensions are given in millimeters.

such a manner as to obtain a thermodynamically stable structure of carbon-free ferrite with highly dispersed fine carbides. It has been patented in France, in the United States and in a number of other countries.

Electrolytic hydrogen pick-up tests conducted in 1953 by Bastien showed the new steel's superiority. It was the material ultimately chosen by SNPA for the tubing of Lacq Well No. 102.

Test Conducted at Pompey Steelworks and Vallourec Research Center

Corrosion Tests

Stress corrosion tests were made on a number of steel specimens in order to classify them according to their life and yield strength. Factors affecting their life include stresses, corrosive medium and physical conditions (particularly temperature and pressure.) One of the main difficulties in making these tests was the determination of the exact magnitude, distribution and gradient of stresses.

Types of Stresses

1. **Jones Test.** A round 1-inch OD bar was placed between two steel strips. These strips varied in thickness from .10 to .15 inch, were 1 inch wide and 4 inches long with two oval holes 2.75 inches distant between centers. The ends of the strips were brought together by two bolts, (see Figure 2).

2. **Cantilever Beam Test (see Figure 3).** A strip measuring 5 inches x .20 inch x .04 inch was clamped in place at a point beginning .80 inch from one end. Weights were hung at the other end with the distance between the clamped end and the weights being four inches. The load was computed to produce the desired stress in the material.

3. **U-Bend Test.** A steel strip .60 inch wide having two holes 5.9 inches apart at their centers was bent into a U shape around a cylindrical bar .80 inch in diameter (see Figure 4). The bending was continued until a gap of only .20 inch existed at the open end. This distance was maintained by fastening the open end with a bolt.
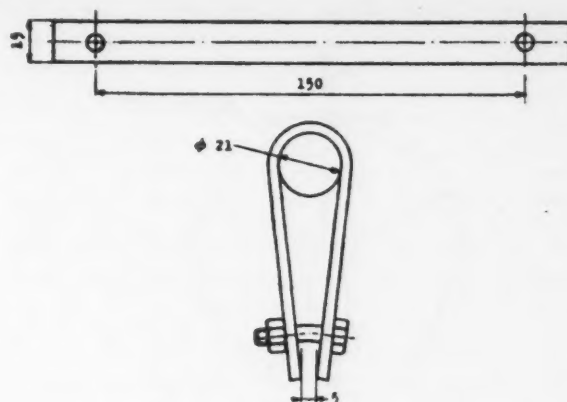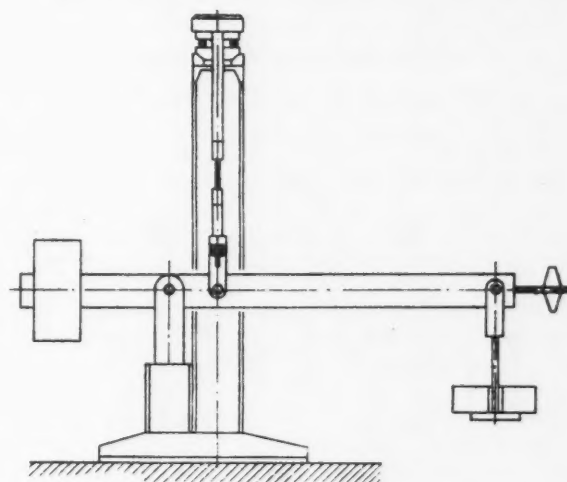
Figure 5—Tensile testing machine.

4. **Expansion Test.** A tube ring with a 1.96 inch outer diameter, .11 inch wall thickness and .40 inch length was press fitted over a 2.04 inch mandrel which was slightly tapered at the front end.

5. **Tensile Tests.**

a. *Machine Tensile Test.* A cylindrical specimen having a .15 inch diameter was placed in the tensile testing machine shown in Figure 5. A load was applied by weights and beams. Tests were conducted with 100 percent, 90 percent and 80 percent of the conventional 0.2 percent strain yield strength. Specimens were jacketed in a rubber sealed plastic chamber and a continuous flow of corrosive medium was maintained in the chamber.

b. *Dynamometric Ring Tensile Test.* A microspecimen was loaded in a dynamometric ring as shown in Figure 6. In this instance the strain relaxation was a variation measurable by a strain gauge. This variation was about 10 to 15 percent when the
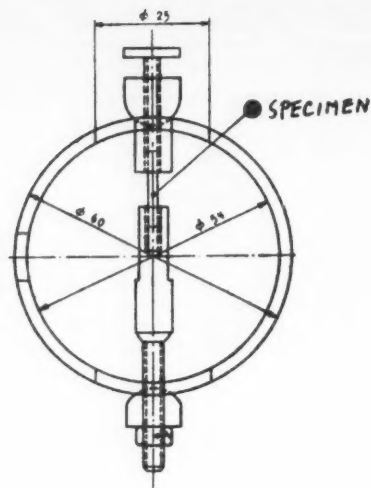
Figure 6—Dynamometric ring tensile test.

Figure 8—Accelerated stress corrosion test in H₂S with 1 percent NaCl present.

Figure 7—Bomb for tests under pressure. Code to letters is as follows: (A) Hole for pressure measurement, (B) Lead seal, and (C) Enameled inside.

load reached the conventional 0.2 percent strain yield strength.

A study has shown that the tensile tests were the most significant of the various tests used because the stresses were known and their distribution was uniform. This type of test is now the one most commonly used in Pompey laboratories.

Corrosive Medium

A number of procedures were used to expose specimens to hydrogen sulfide. These procedures are as follows:

1. **Gaseous Hydrogen Sulfide at Ordinary Pressure and at Room Temperature.** A dilute hydrochloric acid and iron sulfide Kipp gas generator was used with a Durand wash bottle retaining HCl. The gas produced was wet and contained a small amount of hydrogen. Specimens were placed either in a glass vessel tightly sealed at its upper end or in a glass bell upon a water seal. Specimens were examined daily and frequently brushed. Cracked ones were taken out and the exposure time noted. In the case of cantilever beam specimens, brushing was impossible and failures were observed from the outside and the glass bells opened every two weeks. A certain quantity of gaseous hydrogen sulfide was added each day.

2. **Hydrogen Sulfide in Aqueous Solution.** Specimens were placed in a beaker containing distilled water and 5 percent NaCl. Through a glass tube going to the bottom of the beaker, bubbles of hydrogen sulfide from a Kipp generator were continuously introduced. Specimens were taken out each day and brushed and replaced if there were no cracks.

3. **Hydrogen Sulfide Under 1423 psi at 175 F.** A steel bomb enamelled on the inside surface and sealed with lead was used with a pressure gauge. The gauge was later discarded to eliminate leakages. If the mixture introduced remains the same, the same pressure will be reached as with the initial attempt (see Figure 7).

Some 1.22 cubic inches of water, 1.75 ounces of solid carbon dioxide and 2.65 ounces of liquid hydrogen sulfide were in-

troduced into the bomb. This hydrogen sulfide was obtained by cooling crude hydrogen sulfide between −95 F and −110 F after precooling to −22 F in order to eliminate water. In preparing the test the bomb was cooled in liquid nitrogen. Next the specimens were introduced followed by water, solid carbon dioxide and liquid hydrogen sulfide. The top edge coming in contact with the seal was swiftly cleaned and the cover screwed on tightly. After heating for approximately one hour the cover was retightened and the bomb placed in a warm oil bath. The temperature of the bath was increased to 175 F and maintained at that level. After one hour the cover would be retightened if necessary and the temperature maintained at 175 F. The bomb was opened after either 48 hours or 140 hours and the specimens inspected. The maximum time of exposure for the broken specimen was thus obtained and the remaining specimens could be tested again.

Test Results

A great number of steels were tested after different heat treatments. In many instances the specimens had been previously work-hardened. The fiber stress was equally varied. Results are given in Tables 1-6.

Figure 8 gives information relating to tensile tests conducted at 100, 90, 80 and 70 percent of the conventional 0.2 strain yield strength. APS 10 M4 steel was compared to the conventional N-80 steel. Independently of its better behavior under equal or superior load, APS 10 M4 steel, appropriately heat treated, is characterized by the slope of the stress-time to failure curve. In the case of conventional N-80 steel, the stress decrease is followed by only a slight increase of the time to failure; in the case of APS 10 M4 steel, appropriately heat treated, the life increase is considerable.

The consistency of these results has been checked on numerous heats (both on forged bars heat treated in the laboratory and on commercially heat treated and finished pipe). They show that appropriately heat treated APS 10 M4 steel has a very high resistance to high hydrogen sulfide media, compared with other materials in general and with the conventional N-80 steel in particular.

Pipe Manufacture

After the laboratory work was completed, the actual pipe manufacture necessitated special procedure regarding rolling, heat treating and control. A constant cooperation between Vallourec Company,* Pompey steelworks, and SNPA was necessary for these developments which enabled the fabrication of the first 12,500 foot string of tubing. The development was concerned primarily with the pipe manufacture, the heat treating and the machining.

Heat treating must be conducted to obtain the required structure and mechanical properties over the full pipe length (upset ends included.) Machining must be particularly precise to secure absolute tightness of joints under nitrogen pressure of 11,378 psi. All these difficulties were overcome.

Tests on APS 10 M4 Grade 2⅜-inch Tubing

The depth of Lacq No. 102 was 13,415 feet. The 7-inch casing reached a depth of 12,570 feet. Two concentric tubing strings were used for the first tests as a safety precaution owing to the fact that the 7-inch API casing joints had leaked under high pressure in another Lacq well. SNPA set the first 4-inch—6.5 lbs/ft conventional N-80 tubing string upon a Baker packer at 12,500 feet. Then the APS 10 M4 grade 2⅜-inch—4.7 lbs/ft tubing was set inside the 4-inch tubing upon another Baker packer at the same depth.

The 4-inch—2⅜-inch annulus was filled under pressure with gas-oil mixed with Kontol. Production tests were run from August 30, 1955 to February 22, 1956 during which time daily gas production varied from 870,000 to 4,400,000 cubic feet.

Pressures at wellhead were as follows:

    1500 to 2000 psi for 30 days
    3000 psi for 65 days
    4000 psi for 34 days
    5000 psi for 30 days
    6000 psi for 11 days
    7000 psi for 6 days

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* APS 10 M4 pipe is sold by Societe Vallourec, 6, Rue Daru—Paris 8e.

TABLE 1—Time to Failure With Jones Test

Designation	Steel	Yield Strength psi.	Tensile Strength psi.	Wet H₂S, Room Pressure and Temperature	H₂S + CO2 Under 2058 psi at 176 F
				TIME TO FAILURE	
N-80	Conventional grade C — Mn — Mo	> 80,000	≧100,000	For 9 tests failure between 40 and 72 hours. For 2 tests failure at 240 hours	<24 hours
PM-18 PM-17	C: 0.2 — Mn: 1.5 — Mo:0.2 C:0.12 — Mn: 1.5 — Mo:0.2	78,210 ≧ 57,000	106,650 ≧ 78,210	24 hours 72 to 1,000 hours	48 hours
M S V	Half mild, Killed non aging steel	49,770	71,100	Stopped after 2,400 hours, without failure	
K D 2	C:0.2 — Cr: 1.0 — Mo:0.2	> 100,000	> 128,000	48 to 120 hours	
APS 10 A 10% hardened APS 10 C APS 10 C	C:0.12 — Cr:2.0 — Al:1.0 C: 0.12 — Cr:2.0 — Al:0.4 C: 0.12 — Cr:2.0 — Al:0.4	46,926 63,990 56,880	71,100 92,430 85,320	Stopped after 2,400 hours, without failure 120 hours Stopped after 2,400 hours, without failure	Stopped after 48 hours without failure Stopped after 120 hours without failure
APS 10 M4 10% hardened	C: 0.12 — Cr:2.0 — Mo:0.3 Al : 0.3	68,250/ 71,100 80,000/ 91,000	> 85,320 > 100,000	Stopped after 2,800 hours, without failure Stopped after 3,000 hours, without failure	Stopped after 120 hours without failure Stopped after 120 hours without failure

Pressure in annulus at wellhead varied between 2500 and 5000 psi. Gas temperature at wellhead ranged from 113 to 140 F. There was no need to heat by external flow to avoid hydrates.

Inhibitor used was solid Kontol No. 230. Five 2-pound sticks were used every two or there weeks in the initial stages but later this same amount of inhibitor lasted a month. The wellhead was shut an hour and a half each time inhibitor was added; pressure increased to 6000 psi. The iron content in the water from the separator averaged .00004 ounce per liter. This determination is of doubtful validity, however, inasmuch as iron sulfide is partly precipitated when hydrogen sulfide is present.

Condensate for a separator pressure of 800 psi had a gas-oil ratio of 45,000, namely:

Crude oil: 1 gallon per 6000 cubic feet
Water: 1/3 gallon per 6000 cubic feet

Wellhead pressure (shut in) was constant at 7,538 psi.

Results of Tubing Inspection

The tubing was taken out of Lacq No. 102 in March, 1956 and inspected with the help of SN MAREP (Société Nationale de Matériel pour la Recherche et l'Exploitation du Pétrole) to check the internal state of the material. Inspection was made with both the Boroscope and Sonoscope apparatus. A comparison of Sonoscope diagrams before and after the tests in Lacq No. 102 led to the conclusion that the material was free of cracks or incipient cracks.

The surface condition remained practically the same. The pipe lengths were weighed one by one after pressure water cleaning and compressed air drying. The same type of tubing will be used at Lacq No. 104; with an accuracy of 3.5 ounces in 110 pounds, it is estimated that corrosion losses can be ascertained to an accuracy of .004 of an inch with this type of inspection.

Conclusions

Severe production conditions at Lacq necessitated the use of a steel tubing having the N-80 grade mechanical properties but having a better sulfide stress corrosion resistance than the conventional N-80 steel type.

APS 10 M4 steel which exhibited its superiority during laboratory tests, was used in the manufacture of a 2⅜-inch tubing which proved satisfactory for use in production tests in Lacq No. 102. After six months of testing it was found that this steel was resistant to the severe conditions at Lacq. Experience thus confirmed long and difficult research and development work.

TABLE 2—Cantilever Beam Tests With Varying Yield Strength and Fiber Stress

Steel	Yield Strength psi.	Hardening	Yield Strength Fiber Stress	Time to Failure
	145,044	5%	100%	19 to 23 hours
Conventional N-80	130,824/132,246	5%	60% 80% 100%	37 days 7 days 2 days
	89,586/92,430	5%	60% 80% 100%	60 days 43 days 19 days
	142,200/150,732	5%	60% 80% 100%	44 hours 18 hours 18 hours
C : 0.12 Cr : 4.0 Mo : 0.5	106,650/113,760	5%	60% 80% 100%	48 days 10 days 25 days
	76,788/80,000	5%	60% 80% 100%	More than 90 days More than 90 days 70 days
C : 0.4 Si : 1.8 Mn : 0.6	83,187	5%	100%	3 to 6 days
APS 10 M4	89,586	5%	80% 100%	Stopped after 215 days without failure

TABLE 3—U-Bend Tests At Room Temperature and Ordinary Pressure

STEEL	Yield Strength psi.	Stress psi.	Time to Failure
Conventional N-80 Heat-Treated	80,000/92,430	85.320/92,430	20 to 40 days
APS 10 M4 Heat-Treated	81,054/92,430	81,054/93,852	Test stopped after nine months without failure

TABLE 4—Expansion Tests At Room Temperature and Ordinary Pressure

STEEL	Yield Strength psi.	Rockwell Hardness	Time to Failure
J. 55	....	95 B	24 hours
4.0 Cr — 0.5 Mo	....	35 C	4 days
9% Cr	....	99 B	7 days
13% Cr	....	33 C	4 days
1.0 Cr — 0.2 Mo	....	25 C	4 days
Conventional N-80	82,476/85,320	....	48 hours
APS 10 M4 Industrially treated	80,000/91,000	....	Stopped after 15 months without failure

TABLE 5—Stress Corrosion Test in H_2S-CO_2-H_2O Under 1423 psi At 175 F

STEEL	Yield Strength psi.	Test	Time to Failure
Conventional N-80	80,000/85,320	U Bend Waber	<48 hours <22 days
APS 10 M4 Treated	80,000/89,586	Jones	Stopped after 48 hours without failure
		U Bend	Stopped after 48 hours without failure
		Waber	Stopped after 22 days without failure

TABLE 6—Comparative Weight Losses After Long Exposure in Wet Gaseous H_2S At Room Temperature and Ordinary Pressure

STEEL GRADE	Weight Loss Lbs./Sq. Ft./Year	Wall Thickness Decrease In/Year	Sulfide Film Adherence
APS 10 M4 T.S.: 100,000 psi	0.15785	0.00386	Thin film Medium adherence
APS 10 C	0.15539	0.00382	
APS 10 M	0.16357	0.00406	
SAE 1010 non-aging	0.58884	0.01457	Thick film very adherent
SAE 1010 not killed	0.47230	0.01181	
SAE 1020 non-aging	0.44163	0.01102	
SAE 1030 C : 0.15 — Mn: 1.5 Mo : 0.2	0.42528 0.57453	0.01063 0.01417	

Other tests are planned soon at Lacq No. 104 and four other wells with this same tubing.

References

1. *Corrosion*, **8**, 326-360 (1952) Oct.
2. *Revue Metallurgie*, **38**, 225 and 272 (1941).
3. P. Bastien and P. Amiot. *Comptes-rendus Academie des Sciences*, 1031 (1952).
4. P. Bastien and P. Amiot. La fragilité des aciers due à l'hydrogène sulfuré, Fourth World Petroleum Congress, Section VIIB—Preprint 5 (1955).
5. P. Bastien and P. Amiot. *Comptes-rendus Academie des Sciences*, **232**, 69 (1951) Jan.
6. P. Bastien and P. Azou. First World Metallurgical Congress (Detroit, October 1951). *Proceedings ASM*, p. 550.
7. P. Bastien and P. Amiot. *Comptes-rendus Academie des Sciences*, **235**, 1031 (1952).
8. P. Bastien and P. Amiot. *Comptes-rendus Academie des Sciences*, **241**, 1760 (1955).
9. J. Hobson and C. Sykes. *J. Iron and Steel Institute*, **169**, 213 (1951) Nov.
10. P. Bastien and P. Amiot. *Comptes-rendus Academie des Sciences*, **238**, 2238 (1954).

Bibliography

E. Herzog and A. Portevin. Etat actuel du probléme de la corrosion des aciers doux par les nitrates. *Metaux et Corrosion*, No. 158, 171 (1938); Aciéries de Pompey, French patent No. 848,962, registered July 20, 1938.

A. Portevin and E. Herzog. Quelques résultats relatifs à la corrosion des aciers doux dans les nitrates. Journée de lutte contre la corrosion 1938—published in *Chimie et Industrie*, 1939 (Special issue), **41**, No. 8, 471 (1939) Apr.

E. Herzog. Corrosion fissurante d'aciers doux à faibles teneurs en addition dans les nitrates. *Metaux et Corrosion*, No. 282, 29-44 (1949) Feb.

E. Herzog. Rupture des métaux par corrosion et tension mécaniques associées. *Metaux et Corrosion*, No. 325, 329-357 (1952).

E. Herzog. La corrosion fissurante sous tension des aciers doux et des aciers faiblement alliés. Industrial Chemistry Congress, Paris, June 1953.

Corrosion & Anti-Corrosion, **2**, 3-13 (1954) Jan./Feb.

Corrosion & Anti-Corrosion, **2**, 57-68 (1954) Mar./Apr.

Corrosion & Anti-Corrosion, **3**, 91-97 (1954) May/Jun.

Aciéries de Pompey: French patent No. 644,172 (registered March 7, 1953); U. S. Patent No. 360,677.

E. Herzog. Influence de la structure des aciers doux sur lour fragilité sous tension dans l'hydrogène sulfuré. Compte-rendu des séances de l'Académie des Sciences, **241**, 1129-1130 (1955) Oct.

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Coatings for Crude Oil Tank Bottoms*

By R. M. CARTER

Introduction

PROPER selection of coatings is extremely important in protecting the bottom of a field-erected, crude oil tank against internal corrosion. Applying an unsuitable material may mean a large oil loss in addition to structural damage from corrosion.

Frequent inspection to anticipate failure of a coating in service is impractical. To clean a tank for inspection or repair of the coating may cost more than to purchase and apply the material in the first place. Because of the high cleaning cost and operating inconvenience of taking a tank out of service, attention to internal coatings generally is deferred until the tank must be cleaned out for other purposes. Intervals between normal cleaning are often ten years or longer.

This helps to explain why pipeliners are so cagey about trying out new tank coatings and why a supplier's offer to guarantee his product for one, two or three years of service may be received without enthusiasm.

A number of qualities are desirable in a coating material for a tank bottom. Among other things the coating should:

1. Withstand deterioration in the chemical environment in the tank for an indefinite period.

2. Be practical and economical to apply.

3. Accommodate adverse job conditions.

There is a natural tendency to continue using and improving coatings that are known to be successful under service conditions. But frequently it becomes necessary to look for a new material because of dissatisfaction with the durability, cost, or application of a previously used coating. An entirely new service condition also may require a new coating.

When a coating does not perform well, it must be determined whether it is the material or application that is at fault. In many cases a proper selection must be made from a group of untried materials.

Suitability of materials under consideration should be determined by screening them through a realistic chemical testing program in a good laboratory. In addition, promising materials should be evaluated as to ease of application and adaptability to job conditions before they are used in a tank.

Laboratory Evaluation

The data usually furnished on immersion tests in manufactured chemicals are valuable, but only as a guide in selecting the most promising materials for

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Abstract

Corrosion in the bottoms of field-erected tanks handling crude oil continues to be a problem, especially in areas where the oil contains aromatics or other elements that rapidly deteriorate the hot coal tar coatings generally used. New epoxy resin combinations and other coating innovations have brought forth materials that promise to withstand the more troublesome environments and to compete with the older bottom coatings for general use. However, the array of new brand names, chemical terms, unrelated service claims, etc., can become confusing to the operating man faced with the problem of selecting a protective coating for his particular tank.

This paper describes a method successfully used to screen promising materials in the laboratory. It also discusses field conditions, application problems, and other factors that affect the selection and use of successful coatings. **7.5.5**

the laboratory to evaluate. Crude oil and its impurities (basic sediment and water) which collect on the bottom of a tank, contain an infinite number of chemical combinations and concentrations. A material might be proved against any number of possibilities, but be quickly destroyed in service by an unsuspected or unknown agent.

It was desirable to know which of the available materials would perform best when immersed in the liquid environment inside the tank to be coated. This fundamental requirement could be met and materials tested in the natural liquids that are actually in contact with the tank bottom without too much concern over the chemistry involved.

Testing Procedure

This approach was used with satisfactory results when the company was confronted with extensive bottom coating failures in the West Texas division of its pipeline system. Two vats were prepared for immersing coated test panels. One vat was filled

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Figure 1—Coal tar—epoxy resin compound test panel exposed for 197 days in crude and 369 days in brine. Coating was unaffected by exposure and showed no alligatoring or pinholing.
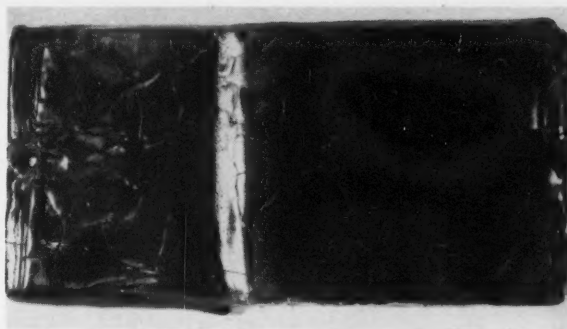
Figure 3—Hot coal tar enamel, Brand B, reinforced with glass cloth. Panel was exposed 197 days in crude and 369 days in brine. Coating alligatored slightly more than Brand A but showed better retention of surface gloss.
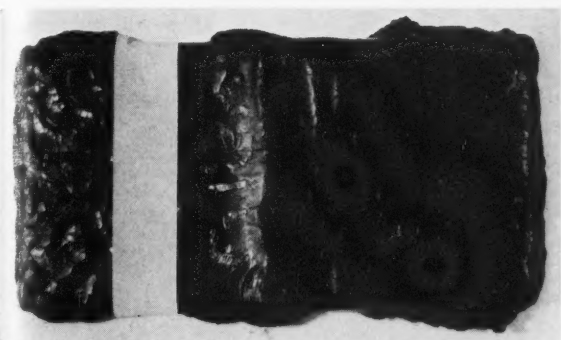
Figure 2—Plasticized hot coal tar, Brand A, mixed with diatomaceous earth and expanded vermiculite. Sample was exposed 197 days in crude and 377 days in brine. This sample showed the least alligatoring of the conventional tars. Left end of panel was patched with a competitive material.
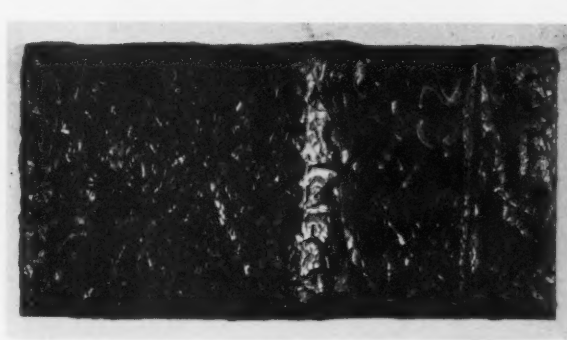
Figure 4—Hot coal tar enamel, Brand C, reinforced with glass cloth. Panel was exposed 197 days in crude and 377 days in brine. Coating was badly alligatored and unsatisfactory.

with equal portions of the Devonian and Ellenberger crudes produced in that area. The other was filled with brinish water drained from the bottom of one of the affected tanks. Steel test panels measuring 4 inches x 9 inches x 1/4 inch were prepared. Each contained a lap-welded joint to provide an irregular surface of a type commonly encountered in tank construction. Coatings applied to the panels were allowed to cure one week before immersion. Four identical panels were prepared for each coating system, thus providing two for initial submersion in each of the two baths. During the test, the coated panels were periodically switched from one bath to the other. Also, the test liquids were frequently renewed.

The testing of materials in these baths was started in July, 1954, and is still in progress. Surprisingly, noticeable effects were observed after very short periods of immersion, thus obviating the accelerated type of testing usually followed for expediency.

Figures 1 through 10 are photographs of representative test panels of coatings that underwent substantial periods of exposure. Their captions describe the material, give the days immersed in each liquid, and include comments on the results.

Coal Tar-Epoxy Resin Combination

The material showing superior performance, in fact the only one totally unaffected by long immersion, is a new coal tar-epoxy resin combination, shown in Figure 1. It is a catalytic-setting material that may be applied in thicknesses of 8 to 10 mils per coat with spray gun, brush, or roller. It has excellent adhesion. As to flexibility, it withstood bending over a 2-inch round mandrel at 100 F and a 6-inch mandrel at —4 F without losing adhesion or cracking. In comparison, a hot coal-tar coating produced by the same manufacturer passed only a 4-inch mandrel at 100 F, and at —4 F lost adhesion and fractured with only slight flexing.

The material that had failed in the actual West Texas crude service was a commonly used, hot-applied, coal tar. Figures 2, 3, 4, and 5 show panels with coatings of this general type from three manufacturers. They were included in the current tests so that the effect of variations in the use of plasticizers and the inclusion of inert fillers could be observed. The degree of surface checking, or "alligatoring," is the basis of comparison. Improvements in these coatings are of interest in connection with their continued use in other areas where they have given good service.

An accelerated type of immersion test completed in 1952 indicated that the rapid deterioration of hot
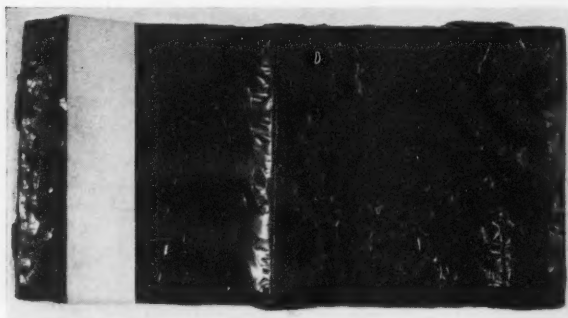
Figure 5—Plasticized coal tar, Brand A, mixed only with vermiculite. Panel was exposed 197 days in crude and 377 days in brine. Coating showed more alligatoring and more cold flow than with diatomaceous earth added.
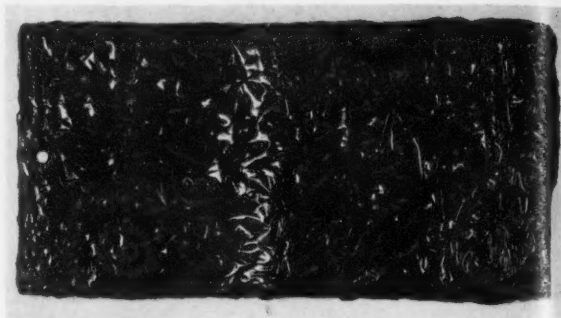
Figure 7—Phenolic resin enamel applied over plasticized coal tar, Brand A, without additives. Panel was exposed 197 days in crude and 369 days in brine. Cracking of enamel was more extensive here than on previous samples which was attributed to lateral movement of softer tar base.

Figure 6—Phenolic resin enamel applied over plasticized coal tar, Brand A, as in Figure 2. Sample was exposed 197 days in crude and 369 days in brine. Enamel was cracked by shrinkage but retained adhesion to coal tar base. Coating was affected mostly by brine.
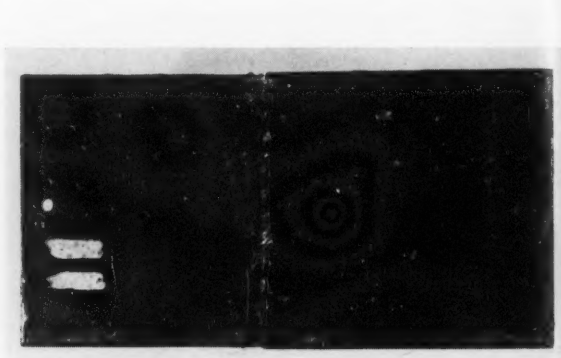
Figure 8—Coal tar-liquid neoprene thin film coating. Panel was exposed 104 days in crude and 192 days in brine. Coating had many small blisters and was unsatisfactory.

coal-tar coatings in West Texas, in contrast to satisfactory service elsewhere, was caused by the uncommonly high percentage of aromatics that occurs in crudes produced in that area.

Figures 6 and 7 are panels simulating the use of a phenolic resin enamel as a top coating to protect a conventional coal-tar base coating against attack from aromatic hydrocarbons. The top coat cracked because of embrittlement and shrinkage; however, there was no loss of adhesion to the base coat. Most of this reaction occurred in the brine exposure. In the preceding accelerated test this phenolic material was unaffected by immersion in a hydrocarbon mixture of 49.1 percent gasoline, 49.1 percent kerosene, 1.3 percent toluene, and 0.5 percent xylene.

Other materials under consideration may show good resistance in the test environments. Some are being screened through preliminary tests—moisture vapor transmission, hardness, impact, flexibility, adhesion, etc. Others are, as yet, considered impractical for tank work because of high unit costs, multiplicity of coats, complicated application, etc. For these reasons they have been shelved pending further development.

Rapid elimination of unsuitable materials has been accomplished in the current testing, but the ultimate serviceability of unaffected materials is, of

course, not yet known. Since the test baths essentially simulate the service environment, the endurance of a material under test should practically parallel the endurance of the same material applied in a tank, insofar as it may be affected by chemical action. To be of utmost value, this type of test should, therefore, be continued indefinitely.

For an operator having a large number of tanks, continuation of the test has obvious economic advantages. In this case some 250 tanks were involved, ranging in size from 500 to 176,000 barrels capacity and averaging 49,000 barrels. Continuation of the test described gives a realistic indication of the endurance of coatings in actual service on inaccessible surfaces inside the tanks. Also, it provides a realistic proving ground that, in conjunction with field experience, enables the user to cooperate with the manufacturers in developing improved coating materials and methods.

Conventional Coal-Tar Coatings

The materials most commonly used over the past 15 years are the well-known, hot-applied, coal tars combined with various plasticizers and fillers. The results have been both good and bad. Useful life of from 3 to 12 years has been obtained. Several 12-year-old applications are still in fair condition.

Where they have proved themselves, hot coal tars have an eminent position and continue to offer stiff competition to the newer products. They very definitely can be used in the specific crude oils in which their suitability has been demonstrated by past performance or by appropriate testing in the laboratory.

A noteworthy improvement has been made in a coating using the so-called "plasticized" type of coal-tar pitch, as was illustrated in Figure 2. Expanded vermiculite, in conjunction with finely ground diatomaceous earth, is being used instead of sand to provide bulk and firmness in the plastic range. The new materials, being lighter in weight, remain in suspension better than sand when mixed with the hot pitch. This allows a homogeneous mixture of the ingredients in the applied coating.

When sand is used, it is difficult to maintain the critical temperature at which the pitch has the proper viscosity to provide a homogeneous mixture. Many spot failures in otherwise sound coating jobs have been attributed to improper mixing of the sand. Areas of coating having insufficient pitch to bind the sand have eroded away and exposed the steel. Excessive cold flow has occurred in areas having insufficient sand.

An improvement also has been made in a competitive coating using a so-called "enamel" type of coal-tar pitch, which does not make use of fillers added on the job. In the new method, two pours of the hot enamel are made. The first pour is covered with a cloth woven from glass fibers of high tensile strength. The loose weave of the cloth allows the second pour, made over it, to be fused with the first pour. The result is an exceedingly strong membrane. It is important to use a limp, unsized, woven cloth that will lie flat on the tank bottom.

Since these coatings are applied $3/16$ inch to $3/8$ inch thick, they readily cover the rough surfaces and lap joints that require special attention when thin coatings are used.

Thin-Film Coatings

The use of a new, more resistant coating is essential where heavy coal tars fail because of inadequate chemical properties. There, the demand for better corrosion protection may allow some leeway for extra cost. For widespread general use, however, new materials and methods still must compete with the old on the basis of convenience and economy.

Why are the terms "new materials" and "thin films" used synonymously? Primarily, it is a matter of economics; since materials more chemically resistant than coal-tar pitch are also many times more expensive, they must be used as sparingly as possible. On the other hand, there are practical limitations on how thin a coating can be applied and yet be an effective chemical barrier. Consequently, job conditions that will have an effect on film thickness are most important in the consideration of "thin film" coatings.

Corrosion-pitted surfaces, riveted joints, lap-welds, patches, weld splatter, etc., require a material with the ability to fill irregularities and to cover projec-
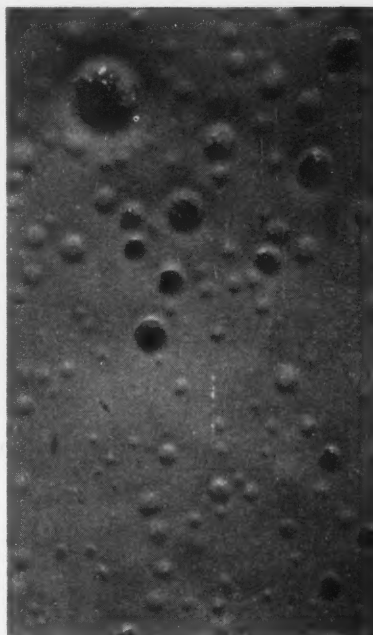
Figure 9—Photomicrograph (35x) of furfural-dehyde, resin. Two coats of this thin film material were spread over primer. Panel was exposed 107 days in crude and 41 days in brine. Coating showed extensive blistering and pinholing and was unsatisfactory.
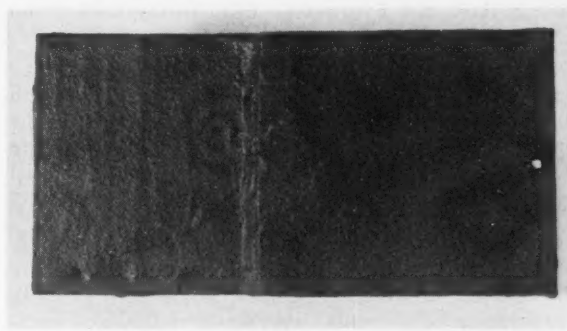
Figure 10—Vinyl mastic coating (one coat over wash primer.) Panel was exposed 376 days in crude and 194 days in brine. Panel has good general appearance. Small rust spots appeared after six days in brine but there was little subsequent change.

tions and sharp edges. Experience indicates that a minimum thickness of 15 to 20 mils is desirable out on the plate surfaces, and that an additional build-up is required along the joints. Of course, this thickness is three to four times greater than that obtained by ordinary paint systems, which are generally associated with the term "thin film." The term is used in a broader sense merely to emphasize the great difference between the entire group of new coatings and the conventional coal tars.

When serious corrosion is present on the under side of the bottom steel (Figure 11), the coating may be called upon to prevent leakage through pit holes that may develop later. Ability to bridge perforations and cracks is also important when riveted joints are to be covered (Figure 12). Leakage is

Figure 11—Underside corrosion in inspection plate cut from ¼-inch thick tank bottom.

Figure 12—Crew applying a hot coal tar coating in an old tank having a riveted bottom.

likely to develop around rivets damaged by underside corrosion, or along the caulking edges of the seams.

The company's practice, when underside corrosion is encountered, is to install external cathodic protection to prevent extensive future damage. Steel defects in evidence are repaired before the coating is applied. However, undetectable pits in an advanced stage may perforate the bottom soon after the tank is returned to service. To be reasonably safe under such conditions, the coating, when cured, should be able to hold the hydrostatic head in the tank when bridged across a gap one-inch wide.

Thin coatings, as well as hot coal-tar coatings, may be strengthened immeasurably by using glass cloth for reinforcement. The increase in cost would be greater for the thin-film coating because of the more difficult application procedure and the extra material required to fill the cloth.

Curing of Materials

One way to classify cold-applied materials is by the manner in which they cure. Some cure through evaporation of solvents; vinyls, phenolics, and ordinary paints are usually in this group. Others cure through chemical reaction, with or without the use of a catalyst or activator. Some of the new epoxy compounds are in this second classification.

In general, materials that cure by evaporation have comparatively lower solids content since they have been cut back with solvents to obtain a flowing consistency. The dried film is quite thin, usually between one and two mils per coat. It is also somewhat permeable because of the minute passageways formed by the escaping solvents. Hence, application costs for a total job are high since a number of coats are required to obtain an adequate and impervious film.

Materials that cure by chemical reaction appear to be the most promising. Their high solids content generally provides a denser and more impervious film and, at the same time, allows a greater build-up per coat. Since fewer coats are required, application costs may be less.

Inert Fillers

One method of obtaining a greater thickness per coat of material is to add inert fillers, such as chopped-glass fibers, ground mica, asbestos fibers, fine silica sand, etc., to form a mastic. Developments now in progress along this line may alleviate the problem of getting a thin-film coating to cover bottom joints and other irregularities adequately and economically.

From the standpoint of economy and convenience of application, the thin-film coatings are more likely to be competitive with hot coal tars in the field of new construction, or on repair jobs where the following conditions exist:

1. There is reasonable assurance that serious underside corrosion will not develop. On new tanks this can be accomplished by proper grade construction (Figure 13). On old tanks it can be investigated by inspecting test plates removed from the bottoms, checking tank-to-soil potentials, and by general observations.

2. There are welded joints present. Thoroughly cleaned lap-weld joints (Figure 14) require less additional build-up of material than do riveted joints. Welding burrs and metal splatter adjacent to welds should be eliminated to further reduce material consumption.

3. Ambient temperatures allow fast curing. Some catalytic-setting materials may require as much as three days per coat to harden when temperatures are in the low thirties.

4. There is general job cleanliness. This may be controlled more easily in a new tank.

The coal tar-epoxy material used by the author can be applied 15 to 20 mils thick under these conditions at nearly the same total cost as regular hot coal-tar applications.

Application Notes

What tolerance for faulty application does, or should, a material have? This is an intriguing ques-
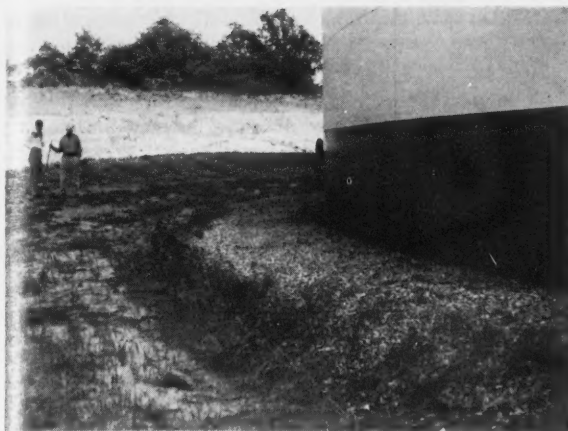
Figure 13—Example of grade designed to reduce corrosion on ground side of tank bottom by keeping the steel surfaces dry and out of contact with corrosive soil. Tank was built on a crushed rock pad 6 inches thick.
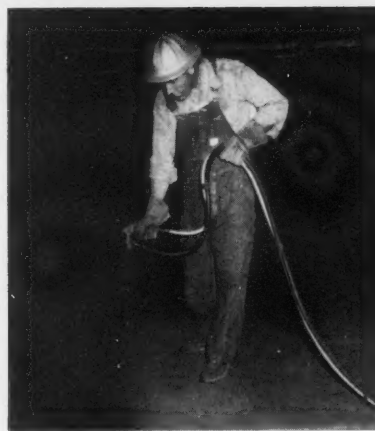
Figure 14—Workman applying a coal tar-epoxy coating on a new lap welded tank bottom.

tion, but one for which reality is likely to be confused with wishful thinking. It is true that tolerance is needed for unavoidable adverse job conditions, and that a wider choice of application methods is needed. Nevertheless the requirement of high standards of workmanship cannot be avoided in protective-coating work.

Good surface preparation, job cleanliness and adherence to specifications are factors having a direct bearing on the successful use of any coating, whether it be "thin film" or "conventional hot coal tar." Materials vary as to versatility in application, but whatever method is used, it must ensure adhesion and continuity of film.

Sandblasting

Sandblasting of surfaces to be coated is recommended in all cases. An intermediate grade of blasting that will remove all foreign matter, corrosion products, and loose scale, but which may permit small isolated areas of tight mill scale to remain, is generally suitable for bottom coating work.

Complete inspection of the cured coating with the aid of an electrical holiday detector also is recommended. A properly adjusted instrument may be used to locate areas of inadequate film thickness, as well as voids in the film.

Availability of crews with the necessary manual skills and equipment may be an important factor in choosing a material. For instance, the art of troweling a heavy hot pitch is quite different from the art of painting with a spray gun. Neither can be properly performed by untrained personnel. Each requires the use of special equipment.

The field use and application characteristics of the new coal tar-epoxy resin compound were described by Murphy.[1] The importance of good surface preparation and superior workmanship in the use of thin materials was stressed in this article.

Hot-applied coal tars, because of their thickness, are generally thought to have a considerable toler-

ance for imperfect application. Still, many spot failures have been traced to this cause. Enlightened supervision and good workmanship are as essential to successful coal tar coatings as they are to the newer thin-film coatings.

Excess Primer

One of the less obvious causes of failure is pouring hot pitch over a small isolated pool of wet primer. Excess primer, collecting in a corrosion pit or a depression along a lap joint, may remain fluid after the rest of the primed surfaces have cured. When contacted by the hot pitch, the volatile solvents in the wet primer suddenly vaporize and form a gas bubble. As the pitch congeals, a void is left that may escape detection because it has been bridged over by a thin membrane of material. Later, after being placed in service, this thin membrane may fail and expose the steel surface under it to a concentrated corrosion attack. In one instance this was thought to have been the cause of failure where 8,000 barrels of oil escaped through a pit leak that developed within three years after the bottom was coated.

Another more common type of spot failure can be attributed to pouring hot pitch over small particles of oily dirt or wax that are present because of improper attention to general job cleanliness. When melted by the hot pitch, the fluids released from such substances float to the top of the coating and leave small passageways through which corrosive elements may later have access to the underlying spots of bare steel. The reference here is to substances that are allowed to foul the steel surfaces after the steel has once been thoroughly cleaned by sandblasting or other means (Figure 12). They may be brought into the tank by clinging to work equipment or to the feet of workmen, or they may drop down from the uncleaned upper parts of the tank.

Adverse Weather Conditions

Internal tank-coating work is not always a "fair weather" proposition. Frequently, emergencies arise that require a tank to be coated in the dead of win-

ter. If a tank develops a leak and needs to be cleaned and repaired, or if a new tank is being erected to take care of a new oil movement or new production, speed in placing the tank in service is of paramount importance. When the weather is unfavorable, there may be a choice of going ahead with an inferior job or of using the tank without a coating. In emergencies, one can seldom afford the luxury of waiting on ideal weather.

Adding tolerance for low temperatures without sacrificing quality no doubt presents difficult formulating problems, but a definite need for improvement exists. It will be up to the manufacturers to supply relief in this direction.

Cold weather causes less inconvenience in applying hot coal tars than it does with thin-film materials. Since the tars are normally made to flow by heating and are quickly hardened by cooling back to atmospheric temperature, no fundamental change in method is required as the air gets colder.

Difficulties with hot coal tars in cold weather include loss of adhesion and cracking as the material cools and hardens. The plasticized type is preferred for use at the lower ambient temperatures.

Cold-applied materials become more viscous with lower temperatures. After adding the manufacturer's recommended maximum allowance of solvent thinner, which in some cases may be none, further thinning to maintain proper flow must come through heating. This requires special equipment and additional procedures. Curing time is increased because of the slower evaporation of solvents, or because of delayed reaction in the chemically cured types. Increased curing time is most objectionable in the multiple-coat system.

Summer temperatures above 100 F also may cause difficulties in handling catalytic-setting compounds. Catalyzed material may gel in the short time between mixing and applying. The result may be not only a loss of high-cost material, but also a loss of expensive equipment made inoperative by the hardened material.

The coal tar-epoxy resin compound previously mentioned can be applied conveniently within a temperature range of 35 to 100 F.

Other Corrosion-Control Measures

Cathodic protection is recognized as a possible means of controlling internal corrosion on tank bottoms, but it should be used in conjunction with good coatings. A unique magnesium anode system has been installed inside six of the company's large tanks (120 ft. in diameter). This system makes it possible to read and to regulate the current output from each anode by means of readily accessible control centers located outside the tanks. Data being collected should allow conclusions on obvious questions about anode performance in this environment, but a report at this time would be premature.

What the company hopes to develop is a combined system wherein cathodic protection will take care of small isolated surface areas exposed by imperfect coating application, or by spot failures. The coating

would in turn supplement the cathodic protection by greatly reducing the current drain, thus allowing an economical installation.

The present anode installations cost about $1,500 per tank. This includes about $700 per tank to provide the control features. It is hoped these control features can be omitted on future jobs after sufficient data for design purposes have been obtained from those in service.

Inhibitors also may have possibilities, but at the moment their use appears to be impractical.

Galvanizing gives good internal protection to tank bottoms in most instances. However, on field-erected tanks its use is limited to small tanks of bolted construction, 10,000 barrels or less, such as those commonly used on producers' leases and at small pipeline pump stations where oil is gathered. Complete galvanizing of new bolted tanks is generally specified, not only to reduce internal corrosion of the bottom, but also to protect the underside of the bottom, the vapor space, and the external surfaces exposed to the atmosphere.

Conclusions

At the present stage of the investigation of coatings, a coal tar-epoxy resin compound and two of the hot-applied coal tars are recommended for use. However, all three might not be considered suitable for the same job because of their differences in resistance to various crude oils, in application methods, and in physical properties.

The coal tar-epoxy material is recommended where highly aromatic crudes, or mixtures of crude and casinghead gasoline, are encountered. Where ordinary crudes are handled, all three materials are generally considered suitable on a competitive basis. In some instances, however, the choice may be limited by the type of crew available, adverse weather, deterioration of the structure, and other local factors.

The proving of a new tank-bottom coating and the development of an application process are costly and time-consuming. Unproved materials may not be used indiscriminately because of the inaccessibility of the coated surfaces, high costs, and serious consequences of failure. But these same conditions, plus the failures that still occur, are the reasons why the search must be continued for better coating systems.

As investigations continue it is anticipated that the number of proved materials will increase. In this way more versatility will be gained in coping with application problems.

It has been learned that the performance of one product should not be the sole basis for judging other products in the same general chemical group. Neither can the ultimate utility of a basic material be known solely from the formulations in which it may now be used. Ingenuity and high-quality workmanship apparently are as important in the formulation and manufacture of improved coatings as they are in the application of the materials on the job.

Reference
1. Patrick Murphy. Thin Film Coating of Tank Bottoms. *Oil and Gas J.*, (1955) Oct. 10.

Effect of Variables in Laboratory Testing
Of Corrosion Inhibitors for Refined Petroleum Products*

By DAVID B. BOIES and J. I. BREGMAN

Introduction

CORROSION PROBLEMS beset the petroleum industry from the well through the refinery to the customer's storage tanks. One of the major areas of corrosion is in the transportation and storage of refined products. After coming from the refinery, these products meet such conditions as transportation by ocean-going tanker, pipeline and tank truck, and storage in refinery or customer's storage tanks. The conditions which affect corrosion are different for each of the above services, and yet the corrosivity of a product, and the value of a corrosion inhibitor often are evaluated by means of laboratory tests under one or two fixed sets of conditions.

Tests which have been described in the literature for the evaluation of corrosion inhibitors for refined products have been limited mainly to the ASTM D665-54 Turbine Oil Rusting Test[1] as modified by military specification and the VV-L-791 Method Water Drop Test[2] and variations of these methods such as water drop type test used by Wieland and Treseder for the evaluation of corrosion in fuel oil storage tanks.[3] Recently the use of electrical testing techniques based on the change of resistance of a test piece with decrease in cross sectional area have been described.[4, 5]

Use, as such, of the military test which consists of a single set of arbitrary conditions limits the value of the results to a measure of the effectiveness of a corrosion inhibitor in an agitated isooctane—sea water mixture at 100 F. This set of conditions generally has little relationship to the actual field corrosion problem (pipelines, tankers, etc.) which needs to be resolved. The water drop test, when used only with the one fixed set of conditions, also is limited in value insofar as application to corrosion problems is concerned. The recent development of the electrical type testing has involved attempts to more closely duplicate field conditions and has allowed the study of a greater range of corrosive factors.

Experience in the evaluation of corrosion inhibitors for various corrosion problems has shown that laboratory tests designed to test these inhibitors should simulate the corrosive conditions existing in the actual problem. It is well known that inhibitors for certain types of corrosive systems are ineffective for others. The complex hydrocarbon-water systems which are present in corrosion problems involving refined petroleum products are no exception to this generalization. Thus, variables which could influence the choice of the proper inhibitors for a specific use may include the temperature, degree of agitation,

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Abstract

In testing corrosion inhibitors for use in refined petroleum products, very careful consideration must be given to the effect of the environmental conditions on the performance of the inhibitors. Only by a careful study of the variables encountered in any specific corrosion problem can an intelligent selection of the appropriate inhibitor be made. Variables studied in this work include the degree of agitation, the concentration of dissolved solids in the water phase, the pH, the temperature, oxygen content, and the nature of the hydrocarbon phase. A brief discussion of testing procedures also is included.

Results for a commercial automotive gasoline, aviation gasoline, jet fuel and a No. 2 fuel oil are discussed. It is shown that some inhibitors which are effective with sea water under dynamic conditions may be completely ineffective with sea water under static conditions. Some inhibitors which are very effective at room temperature may be required at double the concentration at 100 F and may be ineffective at 140 F at five times the room temperature concentration. The concentration of inhibitor required to protect under any specified set of environmental conditions may vary considerably with different refined products. This also may be true for different supplies of products of the same type (e.g., different gasolines).   **5.8.1**

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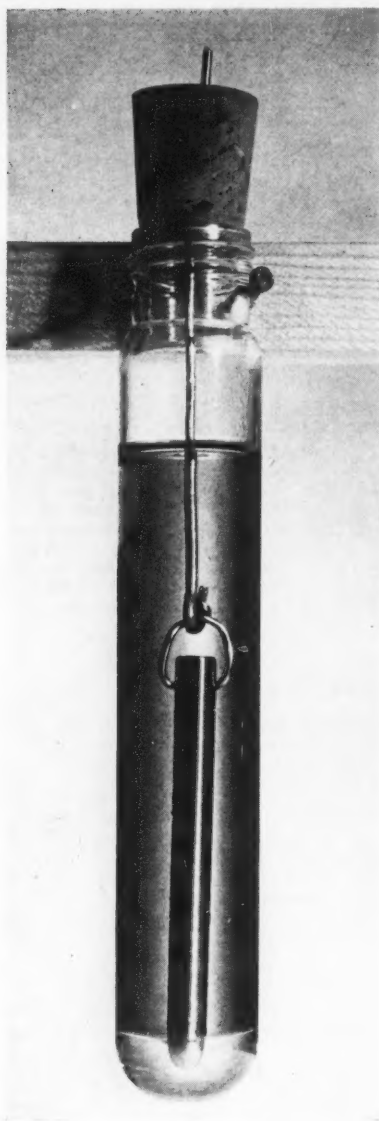
Figure 1—Static corrosion test unit.

type of petroleum product, nature of the water, and the oxygen content of the system. For this reason, a series of tests have been developed in National Aluminate's laboratory which permit the study of inhibitor effectiveness over a wide range of conditions and the selection of the proper inhibitor for the conditions to be encountered in any specific application. This type of testing and results shown by different commercial inhibitors are presented below.

Experimental

Three basic tests were employed, and conditions were varied using these tests. The tests were based on the degree of agitation desired (i.e., static, mild or vigorous agitation). Actual field applications might correspond to one or more of these types of agitation. Storage tanks present a static corrosion problem,

tanker and tank-truck applications involve both static and mild agitation, while in pipelines both mild and vigorous agitation are encountered. The test procedures are as follows:

Static Test

A combination of water, hydrocarbon, and treatment is thoroughly mixed for several hours. The mixture is then allowed to stand and it separates into two phases. A cylindrical mild steel specimen is immersed in the system and allowed to remain in a static condition for 72 hours. The specimen is then removed and visually examined for evidence of corrosion.

Apparatus. A test unit is shown in Figure 1. The equipment consists of: (a) A screw-cap glass tube, 25 x 150 mm, which is used as the test container. The tube is provided with a cork through which is inserted a heavy Nichrome wire hook to suspend the specimen. A one inch piece of 1 mm capillary tubing serves as a vent. (b) A means of mechanically rotating the tube end-over-end at about 45 rpm.

Test Specimen and Its Preparation. The test specimen is a mild steel (SAE 1015) cylindrical rod 0.25 inch in diameter and 2.75 inches long with a 0.125 inch hole drilled through one end. The other end of the specimen is rounded to a radius of 0.125 inch. The drilled end is mounted in a chuck which can be rotated at 1700 to 1800 rpm. The specimen is filed free of gross surface irregularities, if necessary, and then polished with new No. 3/0 emery cloth.

The specimen is removed from the chuck, rinsed with ASTM precipitation naphtha, dried with a clean cloth, and handled thereafter with a clean, dry, lintless cloth.

Test Fluids. The hydrocarbon phase consists of the desired fuel, treated with the inhibitor under test. If the volume of the inhibitor is too small to be measured conveniently, a dilute solution of the treatment may be made, preferably with the hydrocarbon being used. The water phase is either distilled water or synthetic sea water prepared according to ASTM D665-54, having the following composition:

Salt	Grams per Liter
NaCl	24.54
$MgCl_2 \cdot 6H_2O$	11.10
Na_2SO_4	4.09
$CaCl_2$	1.16
KCl	0.69
$NaHCO_3$	0.20
KBr	0.10
H_3BO_3	0.03
$SrCl_2 \cdot 6H_2O$	0.04
NaF	0.003

Procedure. Forty ml of the treated hydrocarbon and four ml of the water are introduced into the screw cap tube. The tube is capped and rotated end-over-end for six hours. The rotation of the tube is then stopped and the two phases are permitted to

separate. The specimen is attached to the hook in the cork and the position of the hook is adjusted so that the specimen hangs with its lower end just above the bottom of the tube, but not in contact with any part of the container. The tube is allowed to remain undisturbed for 72 hours. The specimen is then removed and examined.

Evaluation. If visual inspection reveals no rusting *in duplicate tests*, the treatment is considered to pass the test.

If both specimens from duplicate tests show rusting, the treatment is considered to fail the test.

If one specimen shows rusting, but not the other, tests on two additional specimens are made. If neither of these shows rusting, the treatment passes; if either show rusting, the treatment fails.

Mild Agitation Tests

A weighed flat mild steel specimen is placed in a glass jar together with a mixture of water and hydrocarbon which has been treated with an inhibitor. The jar is then subjected to gentle agitation by means of an oscillating rack for a period of 18 hours. The specimen is removed, cleaned and weighed. Its corrosion rate is then calculated in terms of mils per year.

Apparatus. A test unit is shown in Figure 2. The equipment consists of an 8 ounce glass bottle, 4 inches tall, 2 inches in diameter, with a wide mouth and a screw cap. A 2 inch piece of 8 mm glass tubing is inserted in a hole in the cap to act as a vent. An oscillating rack capable of holding 72 bottles also is used. The motion is approximately elliptical, with a major axis of 2⅝ inch, and a minor axis of about ½ inch, and is repeated 90 times per minute.

Test Specimen and Its Preparation. The test specimen is a mild steel, 22 gauge (SAE 1010) coupon, 1 x 2 inches. The length is chosen such that the specimen does not lie flat in the jar. About three-fourths of the specimen is in the water phase and one-fourth in the hydrocarbon phase when the jar is at rest. The specimen is prepared by sandblasting and rinsing in toluene. It is then weighed to the nearest 0.1 milligram.

Evaluation. The effectiveness of the inhibitor is evaluated by calculating the corrosion in terms of mils (0.001 inches) penetration per year, and comparing it with the corrosion obtained under identical conditions in the absence of an inhibitor. The effectiveness may be conveniently expressed as percent protection; that is, as the percent reduction of the corrosion rate as compared with the test in which no inhibitor is added (the "blank").

In the tests reported here, an inhibitor is considered effective if it gives at least 80 percent protection.

Vigorous Agitation Type Tests

A mixture of treated hydrocarbon and water is vigorously stirred with a cylindrical steel specimen

Figure 2—Mild agitation corrosion test unit.
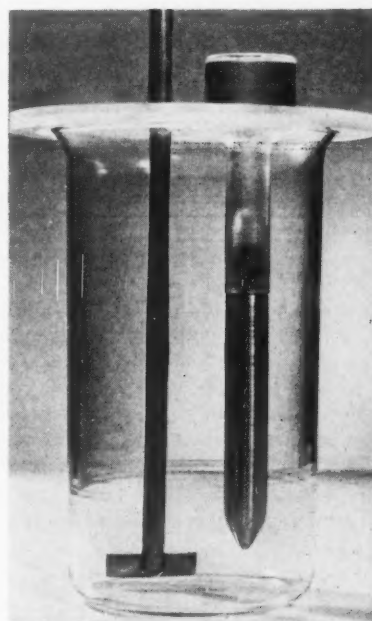
Figure 3—Vigorous agitation corrosion test unit.

immersed therein. After 24 hours the specimen is removed and visually examined for evidence of corrosion.

The test unit is shown in Figure 3. The test procedure and apparatus are described in detail in ASTM Specification D665-54.

Evaluation. The method of evaluation corresponds to that given by DeVerter and Jasek[6] with the exception that only R-1 and R-2 are considered passing. The ratings R-1 and R-2 are defined as follows: R-1: completely rust free, and R-2: trace of few rust spots.

Modifications. The tests reported in this paper as "vigorous agitation" tests are modifications of the above ASTM D665-54 method. The changes are as follows:

1. *Temperature:* The temperature at which the tests were run was chosen with regard to the type of fuel and the service conditions being evaluated.

2. *Weight Loss Evaluation:* One series of tests was run substituting a 1 inch by 2 inch by 22 gauge, SAE 1010-1020 sandblasted mild steel coupon for the regular specimen. The specimens were cleaned after the end of the test and evaluated by means of weight loss. In this series of tests various mixtures of air and oxygen-free (less than 0.001 percent) nitrogen were bubbled through the test fluids.

3. *Military Specification Tests:* These tests are run according to Mil. Spec. 25017. The test procedure is essentially the ASTM D665-54 method except that the fuel is isooctane which has been depolarized with activated alumina, and after adding the test inhibitor, the treated isooctane is leached with 10 percent distilled water, and the leached fuel used as the hydrocarbon phase in the test. The test is run at 100 F. This type of test also was run

using various jet fuels and gasolines as the test medium.

The corrosion inhibitors tested, A, B, and C are of the semipolar, organic, film-forming type. All are commercially available. The results for these three materials are intended to illustrate the type of results which may be obtained over a range of test conditions. These three materials do not exhaust the different chemical types of inhibitors which are available. Different inhibitors might give a different pattern of test results.

Inhibitor dosages expressed throughout this paper are in terms of parts per million (ppm) based on the hydrocarbon. Dosage increments studied vary from test to test but, in general, are 5 ppm below 25 ppm, 25 ppm in the range of 25 to 100, and 100 or more above 100.

Results and Discussion

Agitation

Table 1 shows the results of tests using different degrees of agitation. Static and vigorous agitation tests were carried out on an automotive gasoline-synthetic sea water mixture.

The results shown in Table 1 are extremely significant in that they show that the degree of agitation in the system may have an important effect on the protection afforded by an inhibitor. Thus, while inhibitors A, B and C give comparable protection under conditions where agitation is present, the latter two fail to protect against corrosion at dosages as high as 1000 ppm under static conditions. The dosage requirements for Inhibitor A are increased from 25 to 50 ppm.

From a practical point of view, these results suggest that in choosing an inhibitor for a specific system, the degree of agitation in the system should be carefully considered. Thus, for example, storage tanks which present a completely static system and tankers which have considerable static periods along with periods of agitation would need inhibitors which function like Inhibitor A, whereas for other systems which have continuous agitation or flowing conditions the corrosion inhibiting properties under static

TABLE 1—Effect of Agitation on Corrosion Inhibition in a System of Synthetic Sea Water and Automotive Gasoline

INHIBITOR	DOSAGE (PPM) REQUIRED FOR PROTECTION	
	Static	Vigorous Agitation
A	50	25
B	> 1000	25
C	> 1000	25

TABLE 2—Effect of Total Dissolved Solids (T.D.S.) of the Water Phase on Corrosion Inhibition With Automotive Gasoline (Static Test)

INHIBITOR	PPM REQUIRED FOR PROTECTION AT VARIOUS TDS LEVELS				
	Deionized Water	100 ppm NaCl	1000 ppm NaCl	10,000 ppm NaCl	Sea Water
A	25	25	25	25–50	50
B	100	100	> 1000	> 1000	> 1000
C	100		1000	> 1000	> 1000

TABLE 3—Effect of Water Phase pH on Corrosion Inhibition in a System of Synthetic Sea Water and Automotive Gasoline (Mild Agitation Test)

INHIBITOR	PPM REQUIRED FOR PROTECTION AT VARIOUS pH READINGS			
	3	5	7	8
A	15	10	10	5
B	15	10	10	5

TABLE 4—Effect of Dissolved Air on Corrosion Inhibition in a System of Synthetic Sea Water and Automotive Gasoline (Vigorous Agitation Test)

INHIBITOR	PPM REQUIRED FOR PROTECTION WITH VARIOUS PERCENTAGES OF AIR IN GAS PHASE		
	100 Percent	25 Percent	0 Percent
A	20	10	10
B	20	10	10

TABLE 5—Effect of Temperature on Corrosion Inhibition in a System of Synthetic Sea Water and Iso-Octane (Vigorous Agitation Test)

INHIBITOR	PPM REQUIRED FOR PROTECTION AT VARIOUS TEMPERATURES		
	75 F	100 F	140 F
A	20	20	30
B	15	35	100
C	15	30	100

TABLE 6—Effect of Hydrocarbon Type on Corrosion Inhibition in a System of Synthetic Sea Water and Various Hydrocarbons (Vigorous Agitation Test)

Inhibitor	PPM REQUIRED FOR PROTECTION					
	Heptane	Iso-octane	Cyclo-hexane	Toluene	Automotive Gasoline	No. 2 Distillate
A	15	20	10	15	25	25
B	15	15	30	15	25	35

TABLE 7—Effect of Type of Aviation Gasoline on Corrosion Inhibition

INHIBITOR	Test Conditions	PPM REQUIRED FOR PROTECTION		
		Gasoline No. 1	Gasoline No. 2	Gasoline No. 3
A	Vigorous Agitation—Synthetic Sea-Water	25	20	25
B	Vigorous Agitation—Synthetic Sea-Water	10	10	10
C	Vigorous Agitation—Synthetic Sea-Water	30	15	25
A	Static—Synthetic Sea-Water	50	250	100
B	Static—Synthetic Sea-Water	>1000	>1000	>1000
C	Static—Synthetic Sea-Water	>1000	>1000	>1000
A	Static—Deionized Water	25	25	25
B	Static—Deionized Water	50	100	500
C	Static—Deionized Water	100	1000	500

TABLE 8—Effect of Type of No. 4 Jet Fuel on Corrosion Inhibition

INHIBITOR	Test Conditions	PPM REQUIRED FOR PROTECTION			
		Jet Fuel No. 1	Jet Fuel No. 2	Jet Fuel No. 3	Jet Fuel No. 4
A	Vigorous Agitation—Synthetic Sea-Water	25	70	30	20
B	Vigorous Agitation—Synthetic Sea-Water	20	40	20	20
C	Vigorous Agitation—Synthetic Sea-Water	20	60	20	25
A	Static—Synthetic Sea-Water	100	100	250	100
B	Static—Synthetic Sea-Water	>1000	>1000	>1000	>1000
C	Static—Synthetic Sea-Water	>1000	>1000	>1000	>1000
A	Static—Deionized Water	25	50	10	50
B	Static—Deionized Water	100	250	25	100
C	Static—Deionized Water	100	100	250	50

TABLE 9—Effect of Time on Corrosion Inhibition in a System of Synthetic Sea Water and Automotive Gasoline (Mild Agitation)

CONCENTRATION OF INHIBITOR A IN PPM	WEIGHT LOSS IN MG./SQ. IN. AFTER VARIOUS TIME LAPSES		
	1 Day	3 Days	14 Days
0	9.0	17.9	93.5
2.5	10.2	19.7	67.5
5	3.4	3.6	3.0
10	1.1	0.9	1.0

conditions afforded by Inhibitor A would not be essential.

Water Composition

The effect of varying the total dissolved solids (TDS) content of the water was studied by the static test procedure using automotive gasoline. Waters which were used were as follows:

1. Deionized
2. One hundred ppm NaCl
3. One thousand ppm NaCl
4. Ten thousand ppm NaCl
5. Synthetic sea water

Table 2 shows how the dosage necessary to protect against corrosion may vary considerably with TDS for some inhibitors and only slightly for others.

In Table 2 it can be seen that whereas all these inhibitors were effective to some extent (Inhibitor A was more effective than the other two inhibitors because of the static test conditions) when the water was deionized or when it contained only 100 ppm of NaCl, the only one which showed protection when the TDS of the water was increased to an appreciable amount was Inhibitor A. This suggests that the composition of the water present in the system to be protected may be a critical factor in the choice of inhibitor.

For the inhibitors tested, there is a gradual decrease in corrosion with increasing pH over the range of 5 to 8 as is shown in Table 3. Other inhibitors might behave differently in this respect.

The effect of the pH of the water phase on the dosage of inhibitor necessary for protection was studied by use of the mild agitation test. The water phase was synthetic sea water adjusted to the desired pH while the hydrocarbon phase was automotive gasoline.

Dissolved Air

The effect of oxygen, or more correctly that of dissolved air, was studied by use of the vigorous agitation test modified so as to include measurement of weight loss. Three levels of dissolved air were maintained: one by continually bubbling air through the test fluids, another by bubbling through a mixture of 25 percent air and 75 percent nitrogen and the third using only nitrogen. The water was synthetic sea water and the hydrocarbon was automotive gasoline. The results are shown in Table 4, which appears to indicate that air has an adverse effect on the performance of the organic inhibitors checked. This illustrates that the degree of aeration is another factor which should be considered in the selection of an inhibitor.

Temperature

The effect of temperature on protection by corrosion inhibitors was studied by use of the Military Spec. Test using isooctane and synthetic sea water. Studies were carried out at 75 F, 100 F, and 140 F. This temperature effect, shown in Table 5, is an extremely interesting one. A rapid change in the degree of corrosion inhibition with two of the in-

hibitors takes place over a temperature range which is not an infrequent one for practical problems. The reasons for the sharp drop in protection for these inhibitors as contrasted to the other have not yet been determined. It is likely that the protective films laid down by these inhibitors fail to adhere to the metal surface as the temperature rises. The theoretical reasons for this are beyond the scope of this paper but probably concern:

1. The type of bonding between the inhibitor and the metal.

2. The adsorption equilibrium between the inhibitor and the metal surface.

3. The increased solubility of the inhibitor in both the aqueous and hydrocarbon phases.

4. The change in inhibitor configuration as its energy is increased along with that of the surrounding medium.

Refined Product Composition

Two different sets of conditions were studied here. In one case, a series of different hydrocarbons were compared with an automotive gasoline and a No. 2 distillate fuel oil. In the other, comparisons were made of samples from different suppliers of aviation gasoline and JP-4 jet fuel. In both cases, tests were carried out by the Military Spec. test procedure, at room temperature. Static corrosion tests also were made with the aviation gasolines and jet fuels. The test results are shown in Table 6 for the different hydrocarbons, Table 7 for the aviation gasolines and Table 8 for the jet fuels.

The fact that the effectiveness of a corrosion inhibitor for a hydrocarbon-water system will vary with the nature of the hydrocarbon is brought out in Table 6.

The variation in the amount of inhibitor needed to protect different samples of aviation gasoline is shown in Table 7, while the variation for jet fuels is shown in Table 8. For these aviation gasolines, the corrosivity differs considerably under static conditions. Under agitated conditions, the differences are not nearly as great. The same sort of effect shows up in jet fuels, and here it can be seen that the Jet Fuel No. 2 was much more corrosive than the others. In most of the test cases, larger dosages of the inhibitors were required for this particular jet fuel than for any of the others.

These data on the effect of hydrocarbon composition are of considerable significance. They show the importance of evaluating inhibitors on the actual products concerned. Not only can differences in in-

hibitor performance be expected between different kinds of refined products such as gasolines, distillate fuels, jet fuels, etc., but appreciable differences can exist in products of the same type.

Effect of Time

The change in corrosion rate as a function of time was studied by means of the mild agitation test. Automotive gasoline was used with synthetic sea water. The results for Inhibitor A are shown in Table 9. These results are interesting in that after one day, Inhibitor A appears to be only partially effective at 5 ppm. However, after three or fourteen days, the data show that no further corrosion took place. Data obtained in this way, at several concentrations of inhibitor, as a function of time, are useful in predicting the behavior of a system if the amount of inhibitor added is too small.

The data illustrate that the time factor is another variable which should be considered in the selection of an inhibitor and its concentration.

Summary

It has been shown that laboratory tests designed to study corrosion problems involving refined petroleum products should simulate the corrosive conditions existing in the particular problems involved. Thus variables such as the temperature, degree of agitation, type of petroleum product, nature of the water and oxygen content of the system may influence the choice of proper inhibitors for a specific use. The data on the specific inhibitors tested in this paper serve to illustrate this point. For these three inhibitors, the degree of agitation and the total dissolved solids content of the water were of special importance. Other variables might have a marked effect on other classes of inhibitors.

References

1. ASTM Method D665-54, Turbine Oil Rusting Test.
2. Federal Specifications VV-L-791, Lubricants, Liquid Fuels and Related Products; Methods of Inspection, Sampling and Testing.
3. R. Wieland and R. S. Treseder. *Corrosion*, **10**, 401 (1954).
4. A. Dravnieks and H. A. Cataldi. *Corrosion*, **10**, 224 (1954).
5. G. A. Marsh and E. Schaschl. Laboratory Method for Corrosion Inhibitor Evaluation. *Corrosion*, **12**, 534t (1956) Nov.
6. P. L. DeVerter and A. W. Jasek. *Corrosion*, **11**, 261t-265t (1955).

Any discussions of this article not published above will appear in the June, 1957 issue.

NACE TECHNICAL COMMITTEE REPORTS

First Interim Report

Tentative Recommended Specifications for

Asphalt Type Protective Coatings For Underground Pipe Lines— Wrapped Systems

By NACE Technical Unit Committee T-2H On Asphalt Type Pipe Coatings*

Section 1—Description

1.1 Asphalt wrapped systems for pipe lines shall consist of a prime coat followed by either one or two applications of asphalt enamel in conjunction with one or more layers of reinforcing and protective wrappings. An outer wrap sometimes may be applied in place of or in addition to the inner wrap. When extra protection** is required, additional layers or thicknesses of enamel and wrapping shall be applied. When rock fill is encountered, extra protection** consisting of selected backfill or prefabricated rock shields also may be specified. Kraft paper may be placed on the outside of the wrap to prevent adhesion to adjacent pipes or other objects.

1.2 The wrapping system shall be selected by the engineer and shall conform to one of the types specified below:

a. Where a single wrap is required, it shall be constructed according to the following system:

Single Wrap System

1 coat of asphalt primer
1 coat of hot asphalt enamel $\frac{3}{32}$ inch $\pm$ $\frac{1}{32}$
1 wrap of asphalt saturated felt or asphalt saturated glass wrap completely bonded to the enamel.

b. Where a double wrap is required, it shall be constructed according to one of the following systems:

Single Coat—Double Wrap System

1 coat of primer
1 coat of hot asphalt enamel $\frac{3}{32}$ inch $\pm$ $\frac{1}{32}$
1 wrap of glass mat (embedded in coating)
1 wrap of asphalt saturated felt or asphalt saturated glass wrap completely bonded to the enamel.

Double Coat—Double Wrap System

1 coat of primer
1 coat of hot asphalt enamel $\frac{3}{32}$ inch $\pm$ $\frac{1}{32}$
1 wrap of asphalt saturated felt, asphalt saturated glass wrap, or glass mat completely bonded to the enamel.
1 coat of hot asphalt enamel $\frac{3}{32}$ inch minimum

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* Austin S. Joy, Brumley-Donaldson Co., Huntington Park, Cal., chairman.
* Note: The engineer shall specify the location and extent of extra protection required.

1 wrap of asphalt saturated felt or asphalt saturated glass wrap completely bonded to the enamel.

c. Where more than a double wrap is required, the procedure specified in either of the double wrap systems is modified to permit additional coatings of hot asphalt enamel and wraps of asphalt saturated felt, glass mat, or asphalt saturated glass wrap. Kraft paper may be used for the outside wrap only.

Section 2—Materials

2.1 Primer—The primer shall be composed of a petroleum asphalt base and petroleum solvents, suitably blended to produce a liquid coating which may be applied cold by brushing or spraying and which will produce a suitable bond between the metal and the asphalt enamel. The primer shall have good spraying, brushing and leveling properties and a minimum tendency to produce bubbles during application. It shall be homogeneous, free from water and shall meet the following requirements:

Flash Point (Open Tag), °F, min....................100
Furol Viscosity at 77 F, sec..................50-150

Distillation:
Distillate (percent of total distillate to 680 F)
To 374 F, min...........35
To 437 F, min...........75
To 500 F, min...........87
To 600 F, min...........97

Residue from Distillation to 680 F, Volume Percent by Difference...........30-45

Tests on Residue from Distillation:
Softening Point (Ring and Ball), °F.......160-225
Penetration at 77 F (100/5)............2-25
Solubility in CCl₄, percent, min................99.0

2.2 Asphalt Enamel—The asphalt enamel shall be composed of petroleum asphalt combined with appropriate inert mineral fillers. It shall be uniform in character, free from water and shall not foam when heated to 400 F. It shall meet the following requirements for the grade selected by the engineer when

Abstract

Descriptions are given of various systems using asphalt, physical characteristics of primers and coatings, means of testing characteristics, recommended application criteria and handling of material after coating. An appendix gives a test for settlement of mineral filler in filled asphalt pipe line enamels.
5.4.5

tested in accordance with the methods hereinafter enumerated:

Grade	A	B
Softening Point (Ring and Ball), °F............	210-240	240-260
Penetration at 77 F, 100 g, 5 sec, max.........	14	7
Penetration at 115 F, 50 g, 5 sec, min..........	5	3
Flash Point (Cleveland Open Cup), °F, min......	450	450
Loss on Heating at 325 F, 5 hours, percent, max......	0.5	0.5
Ash, weight percent......	10-40	10-40
Settlement (Ratio of ash in bottom half to ash in top half after 5 hours at 400 F), max.........	2:1	2:1
Flow Resistance:		
Penetration at 85 F, 100 hours, inches, max.......	0.02	0.01
Penetration at 115 F, 6 hours, inches, max.......	0.04	0.02
Electrical Resistance, Salt Water Immersion, 7 days, megohms/ft², min.	1000	1000

2.3 Pipe Line Wrapping—The pipe line wrapping shall consist of asphalt saturated rag or asbestos felt and either unsaturated or asphalt saturated bonded fiberous glass mats as specified by NACE Unit Committee T-2J. Paper as may be used for outside wrap shall consist of 60 lb., 100 percent sulfate, smooth, unsaturated Kraft.

2.4 Approval of Materials—Prior to use, samples of all materials proposed to be used under these specifications shall be submitted to the engineer for test and analysis and no material shall be used until it has been approved by the engineer.

2.5 Methods of Testing—Except as otherwise noted, methods of testing shall be the latest revision of methods adopted by the American Society for Testing Materials.

a. **Asphalt Primer**

Flash Point—Method of Test Approved by Bureau of Explosives, AASHO Method of Test T79

Viscosity—ASTM Method of Test D 88

Distillation—ASTM Method of Test D 402

Penetration—ASTM Method of Test D 5

Softening Point—ASTM Method of Test D 36

Solubility in Carbon Tetrachloride—ASTM Method of Test D 4, except that CC1₄ is used instead of CS₂ as solvent, Method No. 1.

b. Asphalt Enamel

Softening Point—ASTM Method of Test D 36

Penetration—ASTM Method of Test D 5

Flash Point—ASTM Method of Test D 92

Loss of Heating at 325 F—ASTM Method of Test D 6

Ash—ASTM Method of Test D 271

Settlement—See Appendix, Part 1

Flow Resistance—See Appendix, Part 2

Electrical Resistance—See Appendix, Part 3

Section 3—Construction

3.1 Preparation of Surfaces—All oil and grease on the surfaces of the metal shall be removed thoroughly by flushing and wiping using a fresh petroleum solvent and clean rags. After cleaning, the pipe shall be protected from and maintained free of all oil, grease and dirt from whatever source until the pipe has received its final coating. All metal surfaces shall be thoroughly cleaned by blasting, or, when permitted by the engineer, by wire brushing or scraping. Surfaces that rust before a priming coat has been applied shall be reprepared. Adequate air separators shall be used to remove effectively all oil and free moisture from the air supply to the blaster. Any pipe showing faults after preparation shall be set aside for reconditioning or rejection.

3.2 Asphalt Priming—The use of asphalt primer that becomes fouled with foreign substances or has thickened by evaporation of the solvent will not be permitted.

The primer shall be applied uniformly to the clean, dry surface in a manner recommended by the manufacturer and approved by the engineer. Any bare spots or holidays shall be recoated with an additional application of the primer.

The engineer shall require the pipe to be reprimed if undue delay beyond the manufacturer's recommendations or surface contamination occurs between the application of the prime coat and the enamel application. When the primer has dried to an extent acceptable to the engineer, the first flood coat may be applied.

3.3 Asphalt Base Pipe Line Coating Application—The enamel shall be heated in kettles approved by the engineer and equipped with accurate and easily read thermometers.

The enamel shall not be overheated nor shall it be held in the kettle for an excessive period of time. Operating kettles shall be completely emptied at least once each day and cleaned, when necessary, before another charge of unmelted enamel is added; except, in the practice of field patching, the engineer may permit continuous use of a heating kettle not exceeding 50-gallon capacity.

The enamel shall be maintained moisture and dirt free at all times prior to and during the time of heating and application.

In initially loading the kettles the enamel shall be broken into pieces not exceeding 20 pounds each.

In heating the enamel the charge shall be melted and brought up to application temperature without injury to the enamel and in a manner approved by the engineer. The hot enamel shall be thoroughly and continuously stirred. A patching kettle, 50 gallons or smaller, shall be thoroughly stirred with an iron paddle at intervals not exceeding 15 minutes.

3.4 Application of Wrappers—The wrapping shall be applied in a uniform, snug fitting spiral pattern, immediately following the application of the hot enamel.

In the single wrap system the asphalt saturated felt or asphalt saturated glass wrap shall be applied simultaneously with the hot asphalt enamel and remain on the outside surface of the coating.

In the single coat-double wrap system the glass mat shall be applied first and completely embedded in the enamel; immediately thereafter, the asphalt saturated felt or asphalt saturated glass wrap shall be applied and completely bonded to the enamel.

In the double coat-double wrap system the asphalt saturated felt, asphalt saturated glass wrap, or the glass mat shall be applied to the first coating; immediately thereafter the second coating shall be applied and the asphalt saturated felt or asphalt saturated glass wrap immediately applied and completely bonded to both inner and outer wraps.

3.5 Wrap—The overlap at the edges of the wrap shall be as specified by the engineer. No wrinkling in the wrap shall be allowed and all end laps shall be cemented down with hot enamel by an excessive squeeze out to obtain a firm wrapping. All defective spots in the pipe coating shall be repaired to the satisfaction of the engineer. All coating and wrapping operations shall be subject to the approval of the engineer. Samples shall be cut from the coating, at the engineer's discretion, for determination of thickness and bond of enamel and wrap. After the enamel and wrap have been applied, a test with an electric holiday detector shall be made and all coating defects shall be patched as directed by the engineer.

3.6 Electrical Inspection—An electrical inspection of the completed coating shall be made in accordance with procedures to be established by the T-3D-1 Committee of NACE.

3.7 Handling Coating Material and Coated Pipe—All materials shall be transported and stored in such a manner as to prevent damage or contamination.

The coated pipe shall be handled in such a manner as to minimize damage. Wherever the coated pipe is supported, it shall be by means of slings or skids approved by the engineer. All bearing areas shall be inspected and damaged areas repaired.

Whenever the bottom of the ditch contains projecting rocks or hard objects which might puncture the protective coating, where there exists soils that have large volume variations with moisture content (e. g., adobe, clay, etc.) the bottom of the ditch shall be padded with a minimum of six (6)

inches of backfill material free of soils having a large volume variation with moisture content and free from hard objects that might damage the coating.

The coated line shall be lowered in a manner satisfactory to the engineer.

The ditch shall be backfilled around the pipe and to a depth of at least one pipe diameter above the top of the pipe, unless otherwise directed by the engineer, with material free from soils having a large volume variation with moisture content and hard or sharp objects which may damage the coating.

Where directed by the engineer, the use of a "rock shield" or additional layers of enamel and wrapping material may be substituted for 1) padding the bottom of the ditch and 2) using selected backfill materials.

Backfilling shall be conducted at all times in a manner to prevent damage and abrasion to the exterior protection on the pipe.

3.8 Special Operation—Pipe sections, couplings, or fittings shall be joined together and protected in a manner acceptable to the engineer. However, one extra thickness of enamel and wrap shall be required for all sections where the protection is manually applied.

3.9 Special Provisions for Shop-Protected Pipe—Shop coated pipe shall at all times be stored and transported in such a manner as to prevent damage to the coating.

The length of pipe to be left bare at ends shall be in accordance with instructions supplied by the engineer. The exterior coating edges at ends of the pipe shall be scraped and feathered from the bare or primed surface to full thickness of the protective coating over a distance of not less than one (1) inch.

Pipe shall be stored along the trench side on wooden timbers placed under the uncoated ends of the pipe to hold the pipe off the ground.

3.10 Equipment—All equipment used in these operations shall be of a type satisfactory in all respects to the engineer. No equipment shall be used which may cause undue damage to the pipe or protective system.

3.11 Miscellaneous Provisions—Where river weights, supporting or anchoring devices, or special coating material are used, they shall be attached or applied in such a manner as not to damage the protective coating.

Mill coated pipe shall have a reflective surface adequate to minimize softening due to sunlight.

Section 4—Cathodic Protection

4.1 The engineer shall determine the extent of cathodic protection required.

4.2 When cathodic protection is installed, it shall be installed in accordance with procedures to be established by the T-2C Committee of NACE.

Section 5—Maintenance

5.1 Cathodic Protection—The degree of cathodic protection which may be established shall be maintained in accordance with the procedures established by the T-2C Committee of the NACE.

5.2 Coating Repairs—When excavations are made for leak repairs, tie-ins, lateral connections, or any other purposes, all damaged or deteriorated coatings shall be repaired.

APPENDIX

1. Method of Test for Settlement of Mineral Filler in Filled Asphalt Pipe Line Enamels

Scope

1) This method is intended to measure the degree of settlement of mineral fillers from asphalt enamels containing finely divided mineral fillers for the coating of pipe lines.

Apparatus

2) The apparatus shall consist of the following:

a. Glass Test Tube—The glass test tube shall be approximately 25 mm (1 inch) O.D. and 200 mm (8 inches) long.
b. Oven—The oven shall be capable of maintaining a temperature of 400 F.
c. Test Tube Holder—The test tube holder shall be capable of supporting one or more test tubes in a vertical position during the heating and subsequent cooling periods.

Procedure

3) A representative sample of the asphalt pipe line enamel shall be carefully heated to 400 F, stirring to avoid local overheating and to insure thorough mixing and poured into the test tube to a depth of approximately 175 mm (7 inches). The test tube and contents shall be placed in the holder in the oven and maintained in a vertical position for 5 hours at 400 F ± 9 F. The sample shall then be cooled for one hour at room temperature, after which the ash content shall be determined for the bottom half and for the top half. The ash content determination shall be conducted according to ASTM Method of Test D271. The Settlement of Mineral Filler shall be reported as the ratio of the ash content of the bottom half to the ash content of the top half.

2. Method of Test for Resistance of Asphalt Pipe Line Coatings to Flow Under Soil Stress

Scope

1) This method is intended to measure the resistance of asphalt pipe line coatings to flow under the conditions of temperature and load encountered by coatings on buried pipe lines.

Principle

2) The resistance to flow is determined by measuring the distance that a ¼-inch diameter, flat-ended, cylindrical brass rod, exerting a pressure of 2 pounds per square inch, penetrates a sample of the coating at a temperature of 85 F ± 1 F during a period of 100 hours.

Apparatus

3) The apparatus shall consist of the following:

a. Water Bath—A water bath capable of being maintained at temperatures of either 85 F ± 1 F or 115 F ± 1 F.
b. Container—A shallow container, cylindrical in shape and having a flat bottom, in which the specimen is tested. The inside depth of the container shall be somewhat greater than 0.125 inch and the inside diameter shall be greater than 2 inches.
c. Penetration Rod—A flat-ended cylindrical brass rod 0.250 ± 0.002 inch in diameter and weighing 0.100 ± pound.
d. Depth Gage—A depth gage reading to 0.001 inch for measuring the penetration of the rod into the coating.
e. Support—Any supporting apparatus that will allow the sample of coating to remain in a fixed horizontal position in the water bath and the rod to penetrate vertically without appreciable friction, may be used. One part of the support should be suitable for attaching the depth gage which is used to determine the distance that the rod penetrates into the sample.

Preparation of Sample

4) The sample shall be melted at the lowest possible temperature and poured into the container to a depth of 0.125 ± 0.020 inch. The container and its contents shall be allowed to cool in air for one hour and shall then be placed on the support immersed in the water bath and maintained at a temperature of 85 F ± 1 F for one hour.

Procedure

5) With the sample still on its support in the water bath, the end of the penetration rod shall then be placed on the surface of the coating and its initial elevation reading shall be read from the depth gage. Care shall be taken that the rod is not placed on a bubble or surface irregularity. A final reading of the elevation of the rod shall be taken after 100 hours have elapsed. The difference between the two readings shall be recorded as penetration in units of 0.001 inch, 100 hours, 85 F, 2 pounds per square inch. The average of at least three tests, whose values do not differ by more than 0.002 inch for penetrations less than 0.01 inch or by more than 0.004 inch for penetrations greater than 0.01 inch, shall be recorded in inches. The resistance to flow at 115 F, 6 hours, 2 pounds per square inch, shall be determined in a similar manner.

3. Method of Test for Determining the Electrical Resistance of Asphalt Pipe Line Coating

Scope

1) This method is intended to determine the electrical resistance of asphalt pipe line coatings when tested under standard conditions.

Preparation of Sample

2) The sample of coating shall be brought to the specified application temperature and immediately applied, at a uniform thickness of 1/16-inch, to the exterior of a capped ½-inch by a 6-inch steel nipple and to within one inch of the open end.

Procedure

3) Three inches of the coated section shall be immersed in a 1/10 normal sodium chloride solution for one week. At the end of this period, the electrical resistance of the pipe line coating to the passage of current between the sodium chloride solution and the metal nipple, when under a potential gradient not exceeding 6 volts, shall be measured by an ohmmeter having a minimum range of 10 megohms. The electrical resistance of the coating shall be recorded in megohms per square foot.

PREVENTIVE MEASURES, CA

Partial protection is also very desirable in many cases involving poorly coated lines and can be justified by reductions in sinking fund deposit factors due to increased pipe life, in addition to usual savings in operations.

Electrical engineers should anticipate that cathodic protection will effect savings in other corrosion areas. Power plant equipment, cables, substations, docks, ships and other situations involving metals in contact with soils and solutions are fertile fields for the application of cathodic protection and modern techniques of corrosion control

5.2.1-56 CORROSION CONTROL OF STEEL EQUIPMENT. T. R. B. Watson. **Can. Chem. Processing,** 37, No. 10, 46, 48, 50, 52, 54 (1953) Sept.

Describes causes of corrosion and discusses control by means of cathodic protection.

5.2.1-57 CATHODIC PROTECTION LICKS CORROSION. L. C. Werkin. **Petroleum Refiner,** 31, No. 9, 122-124 (1952) Oct.

Cathodic protection, a positive, controllable and inexpensive method of preventing corrosion. There is real money in reducing these losses caused by corrosion-maintenance, replacement costs, over-design of equipment, and product losses. Refinery management and technical personnel must be keenly aware of the creeping inroads of corrosion, and alert to any feasible solution to the problem. Table showing cost estimates and savings resulting from its use on a large open-box-type refinery condenser and a large diameter Dorr clarifier. 9 refs.

CATHODIC PROTECTION OF STEEL. F. Nurse, H. C. K. Ison and T. W. Farrer. ry, No. 40, 972-974 (1952) Oct. 4.

rrent and potential requirements for teel in sea water and in the presence Protection of mild steel in sea ly stages at a relatively noble nsity is sufficiently high, gh a steel anode. If a protection can be a small current sence of the

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5.2.2-1 CATHODIC PRO ANODES. Brochure, June, 1953 tute, 60 East 42nd Street, New

Merits of zinc anodes (cor and with rectified systems) ir ing distribution piping, tr condensers. Practical

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67 Committee Sessions Are Held at St. Louis

Hundreds of members of NACE technical committee thronged through the halls of St. Louis Sheraton-Jefferson Hotel Sunday and Monday attending meetings. Sessions of other committees continued during Tuesday, Wednesday and Thursday at Kiel Auditorium.

The early start Sunday helped some avoid the conflicts, inevitable in most cases, which plagued those who needed to be in two or more places at the same time. Those who tried to get to more than one session meeting the same time found distances somewhat shorter than has been the case at other meetings—and some reported success.

Proceedings at sessions were enlivened by the recent rapid publication of reports. Many groups said reports either were complete and ready for publication or were rapidly nearing that stage.

Among the groups reporting that their findings were ready for publication, or nearly so were:

T-5A on Corrosion in the Process Industries said its task group on acetic acid has completed its report and expects it to be presented at a regional meeting or the national NACE meeting in San Francisco next March.

The hydrofluoric acid task group of this committee has finished a report and will publish it soon. The nitric acid group is preparing a report to be presented at the San Francisco meeting.

An enlarged numbering system for the identification of plastic materials prepared by T-5D was discussed. A part of the system is to be published soon. A questionnaire circulated on plastics in the chemical process industries by T-5D's group on plastic materials of construction has produced results which have been analyzed and are near completion.

T-3G-1 on Cathodic Protection of Ship Hulls has revised its report on cathodic protection of hulls for publication.

A chart outlining characteristics of and making recommendations for coatings in marine atmospheres has been completed and approved for publication by T-6C on Marine Coatings.

T-3B on corrosion products is working on new bibliographies of corrosion products and is preparing a compilation of identification tests for corrosion products.

T-9 on Marine Biological Deterioration Approved

The Marine Borer Conference will become affiliated with NACE as T-9 on Marine Biological Deterioration. The group, after balloting on the question, decided NACE offered the best opportunity for development of its aims. Its technical material will be presented at NACE meetings.

AT ST. LOUIS COMMITTEE MEETINGE: Upper left, at T-2E coupons exposed in products pipe lines are discussed, left to right, A. W. Jasek, Humble Pipe Line Corp., Houston, vice-chairman; Ivy M. Parker, Plantation Pipe Line Co., Atlanta, chairman; W. S. Quimby, Texas Company, New York. At T-6B meeting (upper right) H. C. Dick, Products Research, Service, Inc. New Orleans presides. Lower left, T. R. Stilley, Good-All Electric Manufacturing Co., Ogalalla, Neb., chairman presides at a T-6B meeting. Lower right, T-5D meets with S. W. McIlrath, Diamond Alkali Co., Cleveland, presiding.

NACE NEWS

Chicago October Meeting Plans Are Discussed

Committee Forecasts Strong Program at Regional Session

The General Arrangements Committee responsible for the October 1-4 North Central Region Meeting in Chicago at monthly meetings since September has established most of the important items on the program. R. B. Janota, Swift & Co. and P. E. Henneberry, Amercoat Corp., co-chairmen, report members of Chicago Section are enthusiastic and eager to make the meeting a success. An exhibition is scheduled to be held concurrently with the meeting.

Resources of the Mid-West in men experienced in corrosion technology will make possible a strong program. Among the eight scheduled symposia is one on fundamentals, papers for which will be prepared by men working in the numerous industrial research and educational centers nearby. The other symposia are on Public Utilities, Cathodic Protection, Transportation, Protective Coatings, Water Treatment, Refineries and Pipe Lines.

Also scheduled are round table sessions and several meetings of technical committees.

Special arrangements for registering on Monday evening preceding the first day of the meeting are being made. This is expected to take the place of pre-registration and reduce the long lines of persons waiting to register on the morning of the opening day. A combination badge and program is being developed to eliminate the familiar pinned identification badge.

Announcement of the details of the social hour and banquet will be made during the summer and arrangements have been made for a ladies' program that will not intefere with shopping.

PLANS FOR NORTHEAST REGION'S May 20-22 Conference to be held at Syracuse University, New York are being formulated by this group of NACE members from Central New York Section and the university. Left to right they are: Standing, R. V. Jelineck, Syracuse University; O. R. Broberg, Lamson Corp.; F. C. Jelen, Solvay Process Division; B. W. Smith, Burns Supply Co.; C. C. Ward, Johns-Manville Corp.; R. E. Hewitt, Hotel Syracuse. Seated, Eleanor Ludwig, Syracuse University; Andrew Kellogg, Niagara Mohawk Power Corp.; H. P. Munger, Syracuse University; Carolina Ward, Johns-Manville Corp. Absent at the time the photograph was taken was Jack Burns of Burns Supply Co.

Emphasis on Materials Selection Is Aim at Northeast Region's Conference at Syracuse

Emphasis will be on materials selection at the May 20-22 Northeast Region NACE Conference to be held at Syracuse University, Syracuse, N.Y. The central theme of the conference "Corrosion Control by Choice of Materials," is apparent in early arrangements made for the program.

Central New York Section NACE, which is making plans for the meeting in cooperation with Syracuse University personnel, also has scheduled plant tours with both Solvay Process Division and Carrier Corporation.

A program for ladies has been arranged including a luncheon and demonstration May 20 and a tour of the Onondaga Pottery Company May 21.

Among the scheduled items on the technical program are:

Monday, May 20

Welcoming addresses, F. C. Jelen, Solvay Process Division, Allied Chemical & Dye Corp., Central New York Section chairman; J. D. Bird, The Dampney Co., Boston, Northeast Region chairman and R. A. Galbraith, Dean, College of Engineering Syracuse University.

Corrosion Principles, R. V. Jelinek, professor of Chemical and Metallurgical Engineering, Syracuse University.

Chemical Inhibitors, George E. Best, Mutual Chemical Division, Allied Chemical & Dye Corp., Baltimore.

Selection of Coal Tar Coatings for Protection of Metals in Underground Service, N. T. Shideler, Pittsburgh Coke & Chemical Co., Pittsburgh.

Selection of Materials for Use in High

Purity Water Systems at Elevated Temperatures, J. F. Eckel, Department of Metallurgical Engineering, Virginia Polytechnic Institute.

Corrosion and the Designation of Corrosion Products in a High Pressure Power Plant, R. C. Tucker, Niagara Mohawk Power Corp.

Tuesday, May 21

Materials Selection Problems in the Chemical Industry, F. L. Whitney, Jr., Monsanto Chemical Co., St. Louis.

Effect of Choice of Materials on Lead Cable Sheath Corrosion, T. J. Maitland, American Telephone & Telegraph Co., New York.

Effects of Moisture on Wax Coatings, Joe Surcheck, Dearborn Chemical Company.

Cathodic Protection, by a speaker to be selected.

Plastics in Corrosive Service, K. V. Chamberlain, Tube Turns Plastics, Inc.

Valves in Corrosive Service, W. E. Heilig, William Powell Co.

Round Table Discussion: C. A. Erickson, Peoples Natural Gas Co., moderator; panel: Burke Douglas, Dow Chemical Co.; R. M. Keller, Atlantic Pipe Line Co.; N. T. Shideler, Pittsburgh Coke & Chemical Co.; L. P. Sudrabin, Electro Rust-Proofing Corp. and L. K. Yerger, Niagara Mohawk Power Corp.

Opening sessions will be in the Maxwell Auditorium, Syracuse University.

Additional information is available from: Orrin R. Broberg, Lamson Corp., Syracuse 1, N.Y.

Evening Sessions Set for San Diego Short Course

Two evening sessions will be held in a corrosion short course to be given in conjunction with Western Region's October 23-25 Seventh Annual Western Regional Conference at U. S. Grant Hotel, San Diego, Cal. The sessions, to be held October 22 and 23 is directed to field and non-technical men but should interest technically trained men as well. Large attendance is expected at the evening sessions.

The conference, organized to include parallel sessions as in 1956, will include the customary social hour and banquet October 24.

Air Pollution Agenda

Air pollution and radiation effects will be among the topics discussed during the Twelfth National Industrial Health Conference to be held at Kiel Auditorium, St. Louis, April 20-26.

Papers for 1958 San Francisco Technical Program's 16 Symposia Being Sought Now

Papers are being sought now for presentation at the 14th Annual NACE Conference at San Francisco. Sixteen symposia have been scheduled tentatively by E. D. Verink, Jr., Aluminum Company of America, Pittsburgh, including three symposia not included in programs in recent years.

Three symposia, Marine, Pulp and Paper and Aircraft Industry, are scheduled to be held on the morning of Friday, March 21.

The tentative schedule of symposia has been announced as follows:
Tuesday, March 18—Chemical Industry (Part 1), Oil and Gas Productihon, Protective Coatings, Refinery (Part 1), Pipeline.
Wednesday, March 19—Corrosion Inhibitors, Corrosion Principles, Refinery (Part 2), General Corrosion, (Part 1), Chemical Industry (Part 2), Cathodic Protection.
Thursday, March 20—Elevated Temperature, Plastics, General Corrosion (Part 2), High Purity Water, Power and Communication, General Corrosion and Pipeline Round Tables.
Friday, March 21—Marine, Pulp and

Paper and Aircraft Industry.

Another innovation tentatively scheduled is holding the General Corrosion and Pipeline and Underground Corrosion Round Tables from 7:30 to 9:30 pm Thursday.

Also planned are three education lectures to be given beginning at 4:30 pm on Tuesday, Wednesday and Thursday.

The Fellowship Hour is planned for Tuesday night and the annual banquet for Thursday night. The general business meeting is scheduled to be held beginning at 11:30 am Wednesday.

As usual meetings of technical committees are planned for Sunday and Monday all day.

Irish Talks on Pipeline Coatings at Shreveport

Approximately 36 members and guests attending the February 26 meeting of East Texas Section heard L. B. Irish, of Irish Engineering Service, Shreveport, Louisiana, speak on Protective Coatings for Pipe Lines. Mr. Irish described coating and wrapping materials and the methods of application and effect of extreme temperatures.

Mr. Irish stressed the importance of using cathodic protection in conjunction with protective coatings on pipe lines and pointed out, protective coatings alone would tend to intensify corrosion at holidays, and that leaks would occur sooner than in bare pipe. Cathodic protection of bare pipe in long lines often is prohibitive in cost, Mr. Irish said, because protective coating reduces current requirements to the point that cathodic protection and protective coating used together are economical.

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Widespread and growing interest in corrosion control stems from the need to protect the ever-growing volume of metals exposed in modern industrial plants.

NACE MEETINGS CALENDAR

April

1 North Texas Section. How to Evaluate Corrosion Inhibitors, Jay Simmons, Sun Oil Co., Dallas. At Fort Worth.

2 Shreveport Section. Review of NACE meeting papers, Ned Stearns, D. E. Stearns Co., Washington-Youree Hotel.

4 Pittsburgh Section. Mellon Institute.

16 Chicago Section. Internal Corrosion and Its Measurement, G. A. Marsh, Pure Oil Co., Crystal Lake, Ill.

16 Cleveland Section. Atmospheric Corrosion, R. B. Hoxeng, U. S. Steel Corp.

18 Detroit Section. Industrial Maintenance Paint Development, S. L. Gajownik, Sherwin-Williams Paint Co. Dinner. Annual paint meeting.

23 Central Oklahoma Section.

25 Sabine-Neches Section. Protective Coatings panel. Little Mexico Restaurant, Orange, Texas.

May

2 Pittsburgh Section. Specifications and Testing of Tank Linings, W. P. Cathcart, Tank Lining Corp. Mellon Institute.

10 Philadelphia Section. Walter Luce, The Duriron Co. Poor Richard Club.

15 Greater Boston Section. Spectographic Analysis to Detect Corrosion, Linwood Eikren, Baird Associates. Election of officers. Hotel Beaconsfield.

16 Detroit Section. Demonstration and lecture on microwaves, transistors and the solar battery, Herbert Bumpus, Michigan Bell Telephone Co.

16 Kanawha Valley Section. Titanium —Fabrication and Corrosion Resistance, William Lusby, E. I. duPont de Nemours & Co., Inc. Topette Drive In, Route 60.

21 Chicago Section. Value of NACE Membership, W. F. Fair, Jr., Koppers Co., Inc., NACE past-president. A film on laying a water line in Colorado will be shown also.

21 Cleveland Section. Epoxy Resin Coatings, Ralph Madison, Truscon Laboratories.

23 Sabine-Neches Section. Importance of Human Relations in Industry. Little Mexico Restaurant, Orange, Texas.

27 Central Oklahoma Section.

No date—North Texas Section, annual picnic.
      Lehigh Valley Section. Plant tour.

Teche Section Hears Stone On Corrosion in Oil Wells

The February 27 meeting of the Teche Section was held in the Lafayette Petroleum Club. John D. Stone of Sun Ray-Mid Continent Oil Company, Benton, Louisiana, spoke on Corrosion in Oil and Gas Wells, Methods of Determining Corrosion Damage and Methods of Treating.

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Materials With High First Cost Often Prove Most Economical

When initial material cost is related to expected life and maintenance expense, high first cost materials often prove to be most economical. This point of view was expressed by J. R. Schley, Haynes Stellite Company at a February 19 meeting of Chicago Section attended by 55 members and guests. Mr. Schley, talking on Nickel Base Alloys for Severe Corrosion Service, covered briefly development of Hastelloy's A, B, C, D, E and F series, and the environments in which they could be expected to perform best.

Hastelloy's test program includes exposure of thousands of panels.

Typical corrosion problems, illustrated with slides, were described by Mr. Schley, with indications of the kinds of materials used successfully in solving them.

Five new members were introduced, the chairman of a nominating committee was named and members were asked to return interest questionnaires to help in planning future programs.

The Fellowship Hour was sponsored by M. W. Kellogg Co. with F. M. Ruggles and senior host and D. L. Duncan assisting.

Aluminum Alloys' Properties Are Discussed at Denver

Ralph L. Horst, Aluminum Company of America presented a talk on Physical and Chemical Properties of Aluminum Alloys and Their Applications in Industry at the February 1 meeting of Rocky Mountain Section in the Olin Hotel, Denver, Colorado, attended by approximately 42 members and guests.

During the business portion of the meeting preceding Mr. Horst's presentation, Harold Doll, chairman of the section nominating committee presented the following selections as officers to serve in 1957: John R. Hopkins, Protecto-Wrap Company, chairman; Paul Lewis, Bureau of Reclamation, vice-chairman; and Herbert Goodrich, American Telephone and Telegraph Company, secretary-treasurer.

300 Attend Philadelphia Section's February Meeting

The February 5 meeting of the Philadelphia Section held in the Poor Richard Club was attended by approximately 300 members and guests. Francis J. Honn, M. W. Kellogg Company gave a technical discussion and demonstrated the industrial applications of Kel-F. He spoke first from a chemist's point of view and told of the theoretical reasons for Kel-F's high resistance and later spent considerable time demonstrating methods of application.

Albert S. Barnes of the Bell Telephone Company of Pennsylvania gave a 35-minute talk on the applications of the transistor to modern communication.

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Organizations of corrosion engineers have been founded in England, France, Germany, Italy, Australia and Japan since NACE was established.

Over 260 Attend Edmonton Corrosion Meeting

Houston Section Told Hot Spray Gives Better Coatings

P. L. Lotz, technical director of Socony Paint & Products Co., Metuchen, N. J. told members of Houston Section at a March 5 dinner meeting that hot spray methods produce better coatings for some purposes than those produced by other methods. Apparently, Dr. Lotz said, a 6-mil coating applied in three coats by hot spray is better than one of equal thickness in which thinner coats are applied.

The speaker opened his discussion on "Protective Paint Coatings" by describing several coating systems and explaining why alkyds, vinyls and epoxies are giving better results than older systems based on vehicles of lower molecular weight. A principal reason for the improved performance of epoxies, Dr. Lotz believes, is the nature of the ether linkage, which is more stable than an ester linkage, for example.

Epoxy coatings amine cured at room temperature are giving satisfactory service in corrosive environments, he reported. Coal tar-epoxy compounds with 14-15 mils thickness applied in two coats are giving good results, he said. Some epoxy-coal tar formulations have resisted successfully 1000 hours testing in boiling water. Amine cured epoxies also seem to have fine resistance to hot water.

In response to questions following his talk Dr. Lotz said there is ample evidence that distilled water more severely attacks coatings than ordinary water. He was unable to give an explanation for the greater severity of attack but pointed out that distilled water used frequently in laboratories when a severe test of coatings stability is desired.

Dr. Lotz showed samples of dipped coatings applied to steel and subsequently tested for extended periods in hot water indicating that a minimum thickness for successful service in hot water seems to be 8 mils.

A Houston Section golf tournament will be held in conjunction with the section's annual barbecue in May. Prizes are awarded winners. Those interested in entering should call Robert P. Suman, Pittsburgh Plate Glass Co., Paint Div., Box 21114, Houston. The section generally meets the second Tuesday monthly. The tournament will be held at "Tennwood," recreational park provided by the courtesy of Tennessee Gas Transmission Co.

Advantages of Glass Coatings Are Described

Advantages of using glass coated materials were stressed by F. W. Nelson, A. O. Smith Corp., Milwaukee at a February 4 meeting of North Texas Section. Twenty-six members and 8 guests heard Mr. Nelson describe the chemical and physical characteristics of glass and the advantages and disadvantages of glass coatings. Several examples of glass-coated commercial products were shown.

Beware of Crevices Is First Design Rule Against Corrosion

The First Commandment in design is elimination of crevices—whether they be from lapping, cracking, loose paint or insulation, masked by grease or other foreign matter. These crevices trap liquids that don't dry; that concentrate by evaporation and set up differential aeration cells in trapped water. This opinion was given by F. L. LaQue, The International Nickel Co., Inc., New York at a meeting of Greater Boston Section February 20. Mr. LaQue spoke to 34 members of the section and 32 guests, including nine students from Boston College and Massachusetts Institute of Technology.

Mr. LaQue identified his remarks as his own personal paraphrase of the celebrated address by R. B. Mears, "Design Factors in Corrosion."

Drawing on experience accumulated by International Nickel at its test stations, Mr. La Que said a general survey revealed that 50 to 60 percent of the common and dismaying rust in automobiles is correctible by run-off holes to drain away trapped water. Small crevices associated with large outside areas are particularly vicious, Mr. LaQue pointed out.

As an example of the importance of area relationship between anodic and cathodic surfaces Mr. LaQue cited the case of the Monel hulled yacht that sank while fitting out because, in the hurry to launch the ship, a few steel rivets were used. In a couple of weeks the salt water dissolved the rivets away.

Among his other comments, Mr. La Que noted an unwarranted leaning to zinc over cadmium in salt exposures; that thick films are the most important factor in non-cathodic coatings; that steel exposed to air should contain at last 0.05 percent copper; that paint performance on metal is greatly affected by the nature of the metal. "A principal value of (salt-spray) is that it affords a recordable reason for accepting or rejecting something as long as the reason doesn't have to be sound, Mr. La Que said.

Chairman Harvey S. Miller, New England Hardfacing Co., Brookline of the Northeast Region 1958 Conference Committee reported that plans include simultaneous technical and committee sessions and a banquet. Assignments for the meeting include:

Technical program: Murray Jacobson, Brookline, Mass.; Philip J. Clough, National Research Corp., Cambridge, Mass.; John Swift, A. D. Little, Inc., Cambridge; Boris H. Tytell, Mattapan, Mass.

Technical Practices: Daniel Cushing, Boston.

Publicity and Printing: Walter E. Langlois, Westinghouse Electric Co., Hyde Park; Howard M. Kelley, Fireproofing Corp. of America, Boston; John Nelson.

Registration: Frank Barnwall, Duxbury, Mass.

Eben O. Smith, West Medford, Mass. Entertainment: Bert Rowe.

Six Keys to Corrosion Control Featured at Canadian Sessions

More than 260 persons registered for the Third Annual Canadian Regional Division Corrosion Conference at Edmonton, Alberta February 7-9. Edmonton Section, host to the meeting, was credited with a large part of its success.

Theme of the conference "Six Keys to Corrosion Control" was covered in the following discussions:

Corrosion Theory—Development, J. G. Parr, Associate Professor of Metallurgy, University of Alberta, Edmonton.

Corrosion Theory—Interpretation, M. E. Parker, Consultant, Houston.

Structural Design, M. W. Clark, Canadian Chemical Co., Ltd., Edmonton, Alberta.

Protective Coatings—Organic, K. Tator, Kenneth Tator Associates, Coraopolis, Pa.

Protective Coatings — Pipeline, M. E. Parker.

Environmental Treatment—General, M. W. Clark.

Environmental Treatment—Water, Steam and Condensate, E. G. Compton, Alchem Ltd., Edmonton.

Inhibitors—Organic, G. E. Purdy, Tretolite Co., St. Louis.

Inhibitors—Inorganic, J. G. Hutcheon, Alchem Ltd., Calgara, Alberta.

Non-Corrodible Materials—Heavy Metals and Ferrous Alloys, J. G. Parr, Associate Professor of Metallurgy, University of Alberta.

Non-Corrodible Materials—Light Metals and Alloys, T. E. Wright, Aluminium Laboratories, Ltd., Kingston, Ont.

Non-Corrodible Materials—Non-Metallic, R. A. Ritter, Associate Professor, Chemical Engineering, University of Alberta.

Cathodic Protection, M. E. Parker.

Evaluation Techniques—Laboratory Methods, T. E. Wright.

Evaluation Techniques—Field Methods.

Corrosion Control Economics—General.

The talks were complemented by discussion sessions and a series of exhibits related to the conference theme was arranged around the principal meeting room.

Social events included, on February 6: A reception and banquet with Martin J. Marshall, United Kingdom Trade Commissioner as speaker.

February 8: Luncheon with Mayor Wm. Hawrelak, City of Edmonton, speaker. Hospitality hour with cocktails and entertainment.

February 9: Cocktails and Canadian Regional Division luncheon.

A program for ladies, in addition to events at the MacDonald Hotel, included a film and display of fabrics at Mayfair Golf and Country Club.

M. W. Clark was chairman of the conference committee while F. W. Hewes, Canadian Protective Coating, Ltd., Edmonton, was chairman of the technical program committee. They were assisted by E. E. Moore, E. G. Compton, J. L. Gattenmeyer, M. K. Pidgeon, A. McClure, D. MacQuarrie, J. Stout, J. G. Evans, W. G. Brander, W. H. Seager and H. G. Richardson.

COMMITTEEMEN FOR NORTHEAST REGION November meeting. Left to right, top row, C. L. Dey, H. W. Fritts, F. Murphy; second row, J. M. Bialosky, J. R. Milliken, J. H. Royston; bottom row, V. V. Kendall, National Tube Div., U. S. Steel Corp.; R. B. Hoxeng; L. G. Royston, Royston Laboratories, Inc.

Tidewater Section, and Corrosion Control Committee Hold Meeting

Tidewater Section and the Engineering Subcommittee, Tidewater Corrosion Control Committee met January 16 at Norfolk, Va. with E. W. Seay, Jr., C & P Telephone Co., Richmond, presiding. W. J. Walker, Corps of Engineers, U. S. Army, Norfolk described engineering features of a cathodic protection system on 450 ships moored near Fort Eustis.

C. M. Calhoun, U. S. Navy discussed corrosion problems at Naval shore stations and Mr. Seay reported on the third rectifier and ground bed installation made by his company in the Norfolk area.

R. C. Thayer, Hampton Roads Sanitation District Commission described corrosion trouble experienced with electric motors in which a potential of 0.5 volt existed between all machine frames and other metal structures to ground.

Functions of NACE T-7 Committee were described to the group.

Meetings of the section will be held second Wednesdays in January, April and October, the July meeting being discontinued.

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NACE's Bibliographic Surveys of Corrosion offer a convenient way to survey the world's literature on corrosion control.

Golden Triangle Meeting Committee Is Named

At a meeting February 25 at Penn-Sheraton Hotel, Pittsburgh, plans for the November 12-14 Golden Triangle meeting of Northeast Region were discussed. Committeemen for the event are: R. B. Hoxeng, Applied Research Laboratory, United States Steel Corp., general chairman; J. M. Bialosky, Koppers Co., Inc., Verona, Pa., technical program chairman; J. H. Royston, Royston Laboratories, Inc., Blawnox, Pa., publicity chairman; H. W. Fritts, Aluminum Company of America, New Kensington, Pa., local arrangements; F. B. Murphy, Aluminum Company of America, assistant local arrangements; J. R. Milliken, Climax Molybdenum Co. of Pa., Pittsburgh, printing; C. L. Dey, Koppers Co., Inc., Pittsburgh, registration; W. W. Binger, Alcoa, New Kensington, entertainment; Mrs. V. V. Kendall, National Tube Division, U. S. Steel Corp., ladies' program. Pittsburgh Section officers are ex-officio.

Hot Dip Galvanizers

The 1957 Meeting of American Hot Dip Galvanizers Association was held April 2-4 at Miami Beach, Fla.

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Exhibitions will be held at NACE regional meetings in Oklahoma City and Chicago this fall.

1957

May 20-22—Northeast Region Corrosion Control Conference, Syracuse University, Syracuse, N. Y.

Oct. 1-4—North Central Region, Chicago, Sherman Hotel. Exhibition.

Oct. 1-4—South Central Region, Oklahoma City, municipal auditorium. Exhibition.

October 23-25—Western Region. Seventh Annual Conference, U. S. Grant Hotel, San Diego, Cal.

Nov. 12-14—Northeast Region Fall meeting, Pittsburgh, Pa.. Penn-Sheraton Hotel.

1958

Mar. 17-21—NACE Annual Conference, Civic Auditorium, San Francisco, California.

October 5-8—Northeast Region, Somerset Hotel, Boston, Mass.

October 20-24—South Central Region. New Orleans, Roosevelt Hotel.

1959

NACE Annual Conference, Sherman Hotel, Chicago, Illinois.

SHORT COURSES

June 6-7—Teche Section Short Course on corrosion. Southwestern Louisiana Institute, Lafayette, La.

October 22-23—Western Region. Corrosion Control Course (Evening Sessions) Hotel U. S. Grant, San Diego, Cal.

Southwestern Ohio Section Discusses Liquid Metals

W. D. Manly, Oak Ridge National Laboratory, Metallurgy Division, presented a paper on Fundamentals of Liquid Metal Corrosion—Sodium, Lithium and Lead at the February 26 meeting of Southwestern Ohio Section held in the Colony Restaurant, Middletown, Ohio, and attended by approximately 40 members and guests. Mr. Manly's paper was illustrated.

The March 11 meeting was a joint meeting with the American Institute of Chemical Engineers.

Approximately 25 members and guests attended the January 29 meeting of Southwestern Ohio Section at which Roy O. McDuffie spoke on Metallic Structures and Corrosion. Professor McDuffie supplemented his talk with a series of slides.

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The 10-Year Index to CORROSION, published in 1956, contains more than 4000 reference phrases to material in issues published 1945-54 inclusive.

J. M. PEARSON

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Contributions of J. M. Pearson to Mitigation of Underground Corrosion

Six articles by the late Dr. J. M. Pearson and one by an associate prepared under his leadership are reprinted for the information of new workers and established investigators into underground corrosion problems. Dr. Pearson, recipient of the 1948 NACE Speller Award for achievements in corrosion engineering, is recognized for his outstanding work on problems associated with corrosion of metals underground. The articles, originally published during 1941-44 in The Petroleum Engineer and in Transactions of The Electrochemical Society are reprinted by permission in this book dedicated to him.   •

Papers included are:
Electrical Examination of Coatings on
  Buried Pipelines
"Null" Methods Applied to Corrosion
  Measurement
Determination of the Current Required
  For Cathodic Protection
Concepts and Methods of
  Cathodic Protection, Parts I, II and III
Preventive Maintenance by Systematic
  Pipeline Inspection by
  Donald F. Van de Water

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Miami Section Schedules Two Meetings in 1957

Meetings of Miami Section are to be held in June and September. The June meeting will be in the evening and the September meeting during the day. Wives of members will be invited to attend evening meetings.

A meeting in November is scheduled to last 5 days.

Howard P. Bonebreak, Jr., Aluminum Company of America, Miami, was named program chairman, with members of his committee: Newton D. Bollinger, People's Water and Gas Co., North Miami and Sigmund Miller, University of Miami, Coral Gables. Other committeemen named were: Membership committee: Harry L. Truchelut, Southern Bell Telephone & Telegraph Co., Miami, chairman; Robert L. Whitman, Miami; Bruce Von G. Scott, Insul-Mastic of Miami, Inc., Miami.

E. J. Tilton, Jr., Florida Power & Light Co., Miami will handle publicity and B. M. Botsford, Miami, was named section trustee.

One Regional Meeting Yearly Set in Southeast

Southeast Region will hold one annual meeting yearly, instead of two. Regional by-laws were so amended at a March 4 meeting at Atlanta.

New regional officers named were: Arthur B. Smith, Amercoat Corp., Jacksonville, Fla., chairman; Joseph Frink, Florida Power & Light Co., Miami, vice-chairman; R. C. Martin, Plantation Pipe Line Co., Atlanta, secretary-treasurer. George M. Jeffares, Plantation Pipe Line Co. was appointed to fill the term of Mr. Martin after his transfer out of the region.

Spokane Short Course At Davenport Hotel Apr. 8-11

A Corrosion Short Course will be held April 8-11 at Davenport Hotel, Spokane, Washington. It is sponsored by Technical Extension Services, Washington State Institute of Technology, State College of Washington in cooperation with NACE.

The theme of the course is "Theory and Use of Field and Laboratory Testing Equipment."

13th Annual Conference Report

Over 600 Attend Annual Business Meeting

Successful Year's Activity Reported By Association

More than 600 attended the 1957 Annual Business Meeting of the National Association of Corrosion Engineers. The meeting, profiting by advance planning and notices, drew larger attendance than any previous business meeting and a larger proportional representation than any meeting in recent years.

W. F. Fair, Jr., Koppers Co., opened the meeting with a report on the association's activities during the year and with some predictions of future activities. He pointed to the $23,000 surplus in the 1956 budget, a considerable change from the deficit contemplated when it was adopted. He also cited adoption of a retirement and insurance plan for NACE employes.

Fewer Members Dropped

A. B. Campbell, executive secretary, briefly explained some recent activities in the association. Fewer members were dropped for non-payment of dues in 1956 than in former years, he said. He also reported a 1957 yearbook in preparation to be issued this year, publication of a 10-year index to CORROSION, the collected Pearson papers, a technical committee directory, the contemplated publication of a classified industrial directory, affiliation of the Marine Borers Conference with NACE and contrasted the 942 registrants at the 1950 St. Louis

L. B. Donovan Is Elected To Board of Directors

Lewis B. Donovan, Consolidated Edison Co. of New York, long active in NACE affairs as a regional officer and a member of the NACE board and executive committee has been elected to the NACE board. He will fill the unexpired term of A. L. Stegner, Tennessee Eastman Transmission Corp., Houston, who has become treasurer. Mr. Donovan will represent active membership on the board.

Donovan

Employed by Consolidated Edison since 1923, Mr. Donovan is general superintendent of station construction and shops department for his company. He was Northeast Region chairman in 1950, a regional director and general chairman of the 1951 Conference and exhibition.

He also is active in the American Gas Association, among other groups.

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The NACE Abstract Filing System is used by many organizations.

Costanzo and West Are New NACE Directors

New directors for Northeast and Southeast Regions took office effective the last day of the March Conference at St. Louis. F. E. Costanzo, Manufacturers Light & Heat Co., Pittsburgh and John B. West, Aluminum Company of America, Atlanta are the new directors respectively of the regions.

Mr. Costanzo, an NACE member since 1948, has been active in the Pittsburgh Section as an officer and otherwise. Mr. West, an NACE member since 1947, has had 20 years' experience using aluminum and magnesium in corrosion control fields.

Industrial Directory Set

An experimental issue of a Classified Industrial Directory of firms selling corrosion control materials and services will be included in an issue of CORROSION this summer. The NACE Publication Committee, at a St. Louis session accepted the recommendation of A. B. Campbell, executive Secretary, that the directory be tried this year.

Plans include offering to a selected list of firms the opportunity to put their names in a classified list.

SCENES AT TECHNICAL MEETINGS—Left, M. C. Miller explains the galvanic relationship of metals in soils to about 500; center, W. F. Oxford, Jr. Sun Oil Co., Beaumont, presides at the Oil and Gas Production Symposium; right, several hundred participated in the Pipe Line and Underground Corrosion Round Table discussion. Technical sessions were exceptionally well attended throughout the meeting.
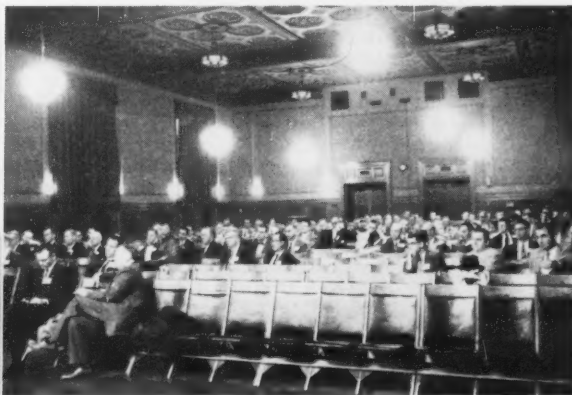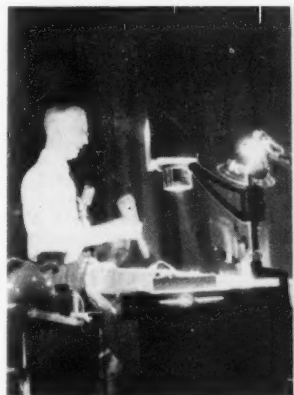
SCENES AT BOARD MEETINGS—Top, at the Sunday, March 10 meeting, left to right, L. L. Whiteneck, Plicoflex, Inc., Los Angeles, vice-president; W. H. Stewart, Sun Pipe Line Co., Beaumont, president and W. F. Fair, Jr., Koppers Co., Inc., Pittsburgh, now past-president. Bottom, standing, E. G. Brink, American Viscose Corp., Marcus Hook, Pa. and seated at his left, John B. West, Aluminum Company of America, Atlanta, directors shown at the March 15 meeting.

Over 600 Attend—

Conference with the estimated 2500 at the 1957 session.

Regional Exhibits Scanned

Requests by regions to hold exhibitions in connection with their meetings will be considered by the NACE board as they are presented. This decision was one of those reached at St. Louis sessions of the NACE Policy and Planning Committee and reported by E. P. Noppel, Ebasco Services, Inc., New York, chairman. Another matter referred to the committee by the board was the question of limiting the funds reimbursed to regions and sections. No action is necessary, Mr. Noppel reported.

Committee Activity Reported

C. P. Larrabee, U.S. Steel Corp., Monroeville, Pa., outgoing chairman of the Technical Practices Committee said committee activity during 1956 was at a high level. More than 50 new activities were initiated, he said.

Also, Mr. Larrabee reported, copies of technical committee reports published during 1957 and subsequent years will be collected and offered for sale in a bound volume.

Among other things mentioned by Mr. Larrabee were:

More technical committees met at regional meetings than before. Indications were good for continued increase in regional sessions.

Some local section committees have been formed.

More than 1000 NACE members now are participating in technical committee work, an increase of 100 percent.

The Yale research project has been completed and the report is under review.

Publication Activity

T. P. May, International Nickel Co., Inc., New York, chairman of the Publication Committee said 550 copies of the 1952-53 Bibliographic Survey of Corrosion have been sold and that the 1954-55 volume is nearing readiness for the printer.

Many subscribers to the NACE Abstract card service say too many cards are being sent and that some changes in the service are contemplated. The question of providing a search service is under continuing study.

New members have been added to the Editorial Review subcommittee, he said, and cited the 168 papers reviewed by this group during 1956 as a major accomplishment. The year past saw NACE news in CORROSION increase one-third, technical section pages 18 percent and abstract and technical committee activities section pages remain about the same.

Section Activity Increases

H. C. Van Nouhuys, Southeastern

Philadelphia Chosen for NACE 1963 Meeting; Southeast Region Scans Atlanta for 1962

The offer of Philadelphia Section to hold the NACE 1963 conference at Philadelphia was accepted by the NACE board at its March 15 meeting in St. Louis. A proposal by representatives of the Atlantic City Convention Bureau was also presented to the board at this meeting.

It was reported also that Southeast Region and the Atlanta, Georgia Section are investigating facilities in Atlanta with the view of proposing that the 1962 conference be held there. The executive committee has been authorized by the board to make a decision on the 1962 meeting.

The board also approved a recommendation by Publication Committee Chairman T. P. May that advertising rates in CORROSION be increased effective with the January, 1958 issue.

The formation of T-8 on Corrosion of Petroleum Refinery Equipment was approved and of T-9 on Marine Biological Deterioration. The latter will be formed about a nucleus now organized as the Marine Borer Conference.

The policy and planning committee recommended that manufacturers be polled on the question of conflicts between regional and national exhibitions and that there was no immediate necessity to legislate on limits for reimbursements to regions and sections.

Chairmen of Standing Committees Are Renamed

Standing committees of NACE this year will have the continued services of their incumbent chairmen for another year. In addition to those announced earlier, T. P. May, The International Nickel Co., Inc., New York has accepted for another year the chairmanship of the Publication Committee and E. P. Noppel, Ebasco Services, Inc., has ac-

cepted chairmanship of the Policy and Planning Committee.

H. C. VanNouhuys, Southeastern Pipe Line Co., Atlanta, Ga. has accepted chairmanship of the Regional Management Committee for another year as reported in January CORROSION.

Also reported earlier was the appointment of E. C. Greco, United Gas Corp., Shreveport, La. as chairman of the Technical Practices Committee and Norman Hackerman, University of Texas as chairman of the Education Committee.

All are ex-officio members of the NACE board of directors. Dr. May also is a director representing active members. Their terms of office began on the last day of the conference.

The immediate past president, W. F. Fair, Jr., Koppers Co., Inc., automatically is chairman of the Awards Committee.

Over 600 Attend—

Pipe Line Co., Atlanta, chairman of the Regional Management Committee said his committee reports 54 sections organized in the association at the end of 1956, including two new ones on South Central Region. Estimated attendance at section meetings was 16,000 and at short courses in which NACE cooperated about 2500.

Efforts will be made in the future to avoid scheduling regional meetings in conflict with one another as to dates, and an activities reporting system will be set up to make possible a better estimate of activities.

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The 10-Year Index to Corrosion, published in 1956, contains more than 4000 reference phrases to material in issues published 1945-54 inclusive.

SOME OF THE 114 BOOTHS at the NACE 13th Annual Exhibition at Kiel Auditorium are shown here. The exhibition was at the same time the largest and most diversified ever presented at an NACE meeting.

Regions Are Asked to Scan Maps for New Section Locations

H. C. Van Nouhuys, chairman of the NACE Regional Management Committee told members of the NACE board of directors at a meeting March 10 in St. Louis that his committee will recommend that regional officers scan maps of their respective regions for blank places where new NACE sections should be organized. Mr. Van Nouhuys cited the addition of the East Texas and Western Kansas sections to South Central Region and said two more sections had joined the number with over 100 members each.

Mr. Van Nouhuys also said he will send to sections a report intended to advise him concerning section activities so that a more accurate check on what happens can be made. The data collected in these reports will be consolidated at regional level before going to his committee, he suggested.

At this same meeting the board:

Set the price of the 1954-55 Bibliographic Survey of Corrosion at $10 for NACE members and $15 for non-members.

Decided that an exhibition will be held in connection with the 1960 NACE national meeting in Dallas.

Made a donation to the Steel Structures Painting Council.

Heard Jack P. Barrett, South Central Regional chairman say that room for 200 exhibits was available at the October South Central Region meeting at Oklahoma City and issue an invitation to NACE to hold a meeting of corporate members during the session there.

Advance Planning Speeds Registration Chore; Total and Paid Attendance Declines Slightly

Advance planning and preparation by the local arrangements committee for the NACE 13th Annual Conference and Exhibition at St. Louis paid off in a smoothly running registration desk and a minimum of confusion. The registration function, benefiting from preliminary work done by E. K. Rice, National Lead Co. and his co-workers, and from the advance registrations prepared at NACE Central office, started off in high gear at 2 pm March 10 and kept waiting to a minimum.

Paid registrations at the St. Louis 13th Annual Conference were a few less than those at the 1956 New York meeting, a preliminary report made by Otto H. Fenner, Monsanto Chemical Co., general chairman indicated. Mr. Fenner said also that gross registration was less than at New York. The figures were: St. Louis—Paid, 1385; New York, 1491; St. Louis—free, 1108; New York, 1388.

A preliminary check showed net income would be somewhat more than contemplated in the budget, or about $34,000.

San Francisco Group Wasting No Time

No time is being wasted by the technical program committee responsible for the 1958 San Francisco 14th Annual NACE Conference. At a meeting March 11 at St. Louis during the NACE conference E. D. Verink, Aluminum Company of America, Pittsburgh reported the committee has:

All symposia selected, including one on coordination of cathodic protection systems to be presented by members of NACE T-7 Coordinating Committee.

Moved the pipe line and general corrosion problems round tables to Friday morning.

Changed the title of the power and communications symposium to "Utilities."

Distributed to symposia chairmen present copies of the NACE Guide, a schedule of deadlines for submission of titles, abstracts, papers and other items on the program.

Arrangements now call for triple simultaneous symposia except on Friday morning when the general round table sessions will be held concurrently also.

Thor N. Rhodin Receives Young Author Award

Thor N. Rhodin, research engineer, Engineering Research Laboratory, Engineering Department, E. I. duPont de Nemours & Co., Inc., received the 1957 NACE Young Author's Award at the annual banquet in St. Louis. His paper "Oxide Films on Stainless Steels," published in CORROSION, Vol. 12, No. 3, on pages 123t-135t received first vote of all committee members whose ballots reached chairman Norman Hackerman on time. Members of the NACE Education Committee selected the paper as the best by an author under 35 years of age published in CORROSION during 1956.

Dr. Rhodin, who holds a BS in chemistry from Haverford College (1942) and an MS (1945) and PhD (1946) in physical chemistry from Princeton University, is active principally in research related to surface chemistry of metals, corrosion, microtechniques, gas adsorption and physical metallurgy. From 1946 to 1950 he was on the staff of the Institute for Study of Metals.

His award-winning paper was a discussion of the theories pertaining to the films on stainless steels and the influence of various corrosive media on the properties of these films.

Editorial Review Committee Membership to Increase

An increase in the membership of the NACE Editorial Review Subcommittee which will almost double its number was approved by the Publication Committee at a March 11 meeting at St. Louis. Also approved was the appointment of a co-chairman who will help the chairman by handling some of the papers routed through the committee.

E. V. Kunkel, Celanese Corp., Bishop, Texas, chairman reported his committee had reviewed and forwarded to the editor of CORROSION 94 papers during the fiscal year and that of these 72 were approved for publication, 17 recommended for rejection and 5 returned without recommendation.

Mr. Kunkel cited resignation of three committee members during the year as evidence the work load was too heavy and that additional members were needed.
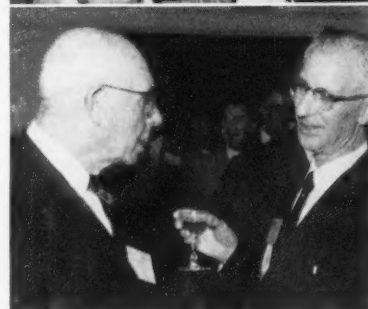
SOCIAL EVENTS included an extensive ladies program. Top, left, some of the lady guests prepare to leave the Sheraton-Jefferson Hotel and right, one corner of the hospitality room at the hotel. (Above) seen at the Fellowship Hour—Top, center, F. L. LaQue, The International Nickel Co., Inc.; right, K. G. Compton, Bell Telephone Laboratories, Murray Hill, N. J. Center, left, H. E. Waldrip, Gulf Oil Corp., Houston; W. F. Rogers, Gulf Oil Corp., Houston; Jack W. Harris, Rockwell Mfg. Co., Houston and Mrs. Waldrip. Bottom, A. B. Campbell, NACE executive secretary and M. C. Miller, Allendale, N. J.

More information about events and decisions at the 13th Annual Conference will be published in May CORROSION. Keep abreast of events in NACE by carefully reading the news section of CORROSION every month. Refer to it for data on NACE activities.

GENERAL NEWS

Carbon Dioxide, Light Affect Copper Corrosion

Two Corrosion Meetings Are Held in Brussels

Two meetings on corrosion were held in Brussels March 29 and April 1 and 2. The March 29 meeting, of Centre Belge d Etude de la Corrosion, concerned the influence of magnetic fields on the course of chemical reactions.

The April 1-2 meeting, involving Cebelcor and the Corrosion Group of the Society of Chemical Industry, Great Britain, listed the following items on its agenda: Activity and Organization of the Corrosion Group; Stress Corrosion Cracking by T. P. Hoar; Research on the Corrosion of Metals by Water, Prof. Ed Leclerc; Role of Corrosion Inhibitors in Water Treatment, E. L. Streatfield; Problems Involved in the Cathodic Protection of Bare Buried Pipe Lines, K. A. Spencer.

Activities of the Corrosion Commission of ABEM, M. Van Rysselberghe and Fontana; Report on the activities of Cebelcor, M. Pourbaix; Control of Corrosion in Industry; J. Strebelle, general discussion.

Corrosion Topics Listed For Radiation Colloquium

Some of the items on the agenda of the Colloquium on the Effects of Radiation on Materials, Johns Hopkins University, Baltimore, Md. are:

27 March—Metallic Materials
Radiation Effects on Physical and Metallurgical Properties of Metals and Alloys, E. S. Billington, Director, Solid State Physics Div., Oak Ridge National Laboratory.
Influence of Radiation on Corrosion Behavior and Surface Properties of Metals and Alloys, M. Simnad, General Atomics Corp.

28 March—Non-Metallic Materials
Effects of Radiation on Behavior and Properties of Polymers, A. Charlesby, Tube Investments, Ltd., Cambridge, England.

29 March—Reactor Components
Kinetics of Gamma-Induced Graft Copolymerization of Vinyl Acetate to Teflon, A. Restaino, Martin Nuclear Division.

Texas University to Hold Industrial Radiation Meeting

An Industrial Radiation Conference will be held May 18 at University of Texas, Austin, sponsored by Civil Engineering Department, University of Texas; Division of Occupational Health, Texas State Dept. of Health; North and Gulf Coast Sections, American Industrial Hygiene Association.

Disposal of radioactive wastes is among the problems to be considered.

Translation Center Grant Is Received

A grant of $20,350 has been made to Special Libraries Association for the support of a Scientific Translations Center at John Crerar Library, Chicago. The center, directed by John P. Binnington, librarian of the Brookhaven National Laboratory, will act as a depository for translations contributed or loaned.

Originally established in 1953, the center at present has a pool of 6000 translations. Translations from the Russian, now held by Library of Congress, will be transferred to the center.

Transcription Monthly, a periodical issued by the center, lists translations available in the pool.

X-Ray Analysis Conference Set August 7-9 at Denver

The Sixth Annual Conference on Industrial Applications of X-ray Analysis will be held August 7-9 at the Albany Hotel, Denver, Col. The conference is sponsored by Metallurgy Division, Denver Research Institute, University of Denver.

Technical material to be covered pertains to X-ray absorption, diffraction and fluorescence analysis. Papers will be considered if received before May 1, 1957 by James P. Blackledge, Head, Metallurgy Division, Denver Research Institute, University of Denver.

NYU Schedules April 13 Nuclear Energy Session

Engineering aspects of nuclear energy will be considered at a one-day symposium at New York University's College of Engineering Saturday, April 13. NYU and Metropolitan Section, American Society of Mechanical Engineers are sponsors. Registration information can be obtained from Fred Landis, New York University College of Engineering, University Heights 53, N. Y.

Air Pollution Conviction Rate Exceeds 96 Percent

A conviction rate of 96.8 percent for 854 complaints of air pollution control violations in Los Angeles County was reported for the July-September quarter by the Los Angeles Air Pollution Control District.

Complaints were filed against such sources as chemical and refinery equipment, rendering plants, concrete batch plants, paint spray booths, electric steel furnaces, hot asphalt plants, heat treating plants, ferrous and non-ferrous foundries, incinerators, open fires, smoking autos and Diesel trucks.

Report Issued on Research Council's Copper Crystal Probe

First year's work on the first research project of the Corrosion Research Council into "Fundamental Corrosion Reactions at the Surfaces of Metals in Selected Environments," has developed several interesting aspects. These are described in the First Annual Progress Report on the project made by Jerome Kruger, in charge of the research sponsored jointly by the Corrosion Research Council and the National Bureau of Standards.

Why do carbon dioxide and the kind of light impinging on the corroding surface influence corrosion behavior?

What is the mechanism by which films are able to grow at room temperatures in oxygenated water at rates comparable to those grown at much higher temperatures in dry oxygen?

What is the origin of and the reason for the special locations with respect to the surface of oxide nuclei observed in microscopic studies?

These questions are among those developed during the first year's work reported to have cost $24,134.

The progress report detailed methods by which single crystals of 99.99 percent pure copper were grown and initial experiments growing and observing corrosion on the surfaces of the crystals in room atmospheres and in controlled atmospheres. Descriptions of the equipment developed for the research are given.

An effort was made to determine through interference colors and by microscopic and x-ray diffraction methods whether the various planes of the crystal surface differed in the types and thickness of films formed.

One experiment indicated that films formed on the crystal in the dark appeared to become thinner when exposed to light from a 3200 degree K lamp. Oxidation films in the lighted areas of crystals differed from that in dark areas.

The project is to be continued during 1957 with half of the funds coming from the Corrosion Research Council and the other half from Bureau of Standards funds.

Lead Ceramics Research

Research on lead ceramics will be carried on by a fellowship at Department of Ceramic Engineering, University of Illinois, sponsored by Lead Industries Association. Prof. Andrew I. Andrews, head of the department, will be in charge.

Gas Technology Course Set

The Twelfth Annual Short Course in Gas Technology has been scheduled by the Texas College of Arts and Industry, Kingsville, May 29-31.

April,

BOOK NEWS

Symposium on Steam Quality. 49 pages, 6 x 9 inches, Paper. December, 1956. Publication No. 192. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. Per copy $1.75. Four papers presented at a symposium June 21, 1956 on Steam Quality are presented: Measurement and Purification of Steam to 0.01 ppm Total Dissolved Solids, W. B. Gurney. Steam Purity Determination by Trace Techniques, E. E. Coulter and T. M. Campbell. Comments on Corrections to Steam Conductivity Measurements, R. O. Parker and R. J. Ziobro. Construction and Operation of Larson-Lane Steam Purity and Condensate Analyzers, A. B. Sisson, F. G. Straub and R. W. Lane.

Electrochemical Affinity. Studies in Electrochemical Thermodynamics and Kinetics. In English. 109 pages, 6½ x 10 inches. By Pierre Van Rysselberghe, Department of Chemistry, Stanford University, Stanford, Cal. 1955. Published by Hermann & Co., 6, Rue de la Sorbonne, 6, Paris, France. Per copy, French Francs, 1250.

This monograph of 110 pages presents the essentials of the thermodynamic theory of galvanic cells, electrolytic cells and single electrodes on the basis of the thermodynamics of irreversible processes. The method used lends itself particularly well to the study of simultaneous electrode reactions and applications to corrosion processes are briefly outlined.

Electrochemical conventions are discussed in detail. The fundamentals of the kinetics of electrode processes are outlined, the special case of hydrogen overvoltage being gone into at some length. The connections between the thermodynamics of irreversible processes and electrochemical kinetics are used to the fullest possible extent.

A final chapter deals with thermoelectrochemistry and in particular with cells which are the seats of temperature gradients. The terminology and general method of presentation are those initiated by De Donder and used already in another monograph by the present author (with Prof. Th. De Donder) entitled "Thermodynamic Theory of Affinity" (Stanford University Press, 1936).

Paint and Varnish Course

A short course in Paint and Varnish Technology will be offered by the School of Chemical and Metallurgical Engineering, Purdue University, June 24-28.

Zinc Institute Meeting

American Zinc Institute will hold its 39th Annual Meeting in Chicago April 25-26 at Drake Hotel. First morning's session will be held jointly with Lead Industries Association and The Galvanizers Committee.

Ohio University Conference

The Fourth Annual Conference of Engineers and Architects, sponsored by the College of Engineering at Ohio State University is scheduled May 3 on the campus.

NEW PRODUCTS

Equipment Services   **Materials Literature**

Foote Prints, a periodical published by Foote Mineral Co., 18 West Chelten Ave,. Philadelphia 44, Pa. includes in Vol. 28, No. 2 articles on electromanganese, manganese-bismuth and an article on titanium, zirconium and hafnium. Lithium metal is described in another article. Extra copies are available on request.

Ker-Chro-Mite AL, a chromate conversion coating for aluminum and its alloys, gives a strong protective coating to aluminum which is suitable as a base for paints or as a corrosion resistant finish. It is made by Kosmos Electro-Finishing Research, Inc., 140 Liberty St., Hackensack, N. J.

Harco Corp., Cleveland has been named to distribute Dow magnesium anodes for corrosion control in the North Central territory.

NRC Metals Corp., formerly a wholly-owned subsidiary of National Research Corp. is now owned jointly by the latter firm and Columbia-Southern Chemical Corp. as equal stockholders. The firm will produce and sell to the Atomic Energy Commission and other customers zirconium and hafnium metals. NRC metals has under construction near Pensacola, Fla. a plant designed to produce hafnium and zirconium in sponge form for melters and fabricators. The

zircon sand used as a raw material is available from Florida ore beds.

Planisol, a chemical detergent marketed by Dunham Chemical Co., a subsidiary of National Cylinder Gas Co. will permit tankers to load cargoes of chemicals almost immediately after unloading a cargo of crude oil, the company says. The process includes cleaning tanks with a hot water solution of the chemical sprayed into them.

Electrical Cable Splices tailor made in the field now can be protected against the environment with an epoxy resin material. The technique, developed by Minnesota Mining and Manufacturing Co., 900 Fauquier St., St. Paul 6, Minn., involves successive wrappings of openscreen tape, liquid-impervious plastic tape and low stretch tape. The liquid impervious tape covers an injection fitting through which the plastic is injected with a hand-operated pressure gun. All components of the splice are available from Minnesota Mining.

Tinker & Rasor, San Gabriel, Cal. has developed a conductive silicon electrode for holiday detectors used to inspect flat coated surfaces. It replaces the wire brush electrodes used during the past 25 years and permits scanning such coatings as hot bitumens, which will not adhere to the silicon due to its non-

wetting property. The electrode, which looks and feels like black rubber, is molded around a metal plate which has mounting holes for bolting the electrode to a wand. It holds its shape and conductivity in temperatures from —20 to plus 450 F. Made in 4, 8, 12 and 16-inch widths with phenolic plastic wand handles, the electrode is flexible enough to conform to irregular surfaces.

American Potash & Chemical Corp. plans to construct a 5 million sodium chlorate plant at Aberdeen, Miss.

Alcoa is now producing polyethylene covered aluminum conductor, in single wire and stranded types in a large range of sizes. Thickness of the coating varies to customer specifications.

Avco Manufacturing Corp. broke ground for its $15 millions research and development center at Wilmington, Mass. on February 18.

Acheson Colloids Co., Port Huron, Mich. is making two new dispersions of glass in isopropyl alcohol, which, when applied at room temperatures form a dry, continuous film which inhibits oxidation and surface contamination during a heating cycle. They form protective coatings for forgings of special alloy steels, titanium and other metals sensitive to oxygen and gases at high temperatures.

Tri-Point Plastics, Inc., 175-77 I. U. Willets Road, Albertson, L. I., New York, is now machining Teflon to tolerances up to 0.0005-inch.

Aluminum welded into a hull for a 55-foot towboat is expected to give the vessel 20 percent less draft with the same dimensions and horsepower as conventional workboats of other materials. Bryant Boats, Inc., Bayou La Batre, Ala. built the hull for use in South Louisiana marshes.

Flex-O-Tube Division, Flexonics Corp., Maywood, Ill. has developed a new line of Teflon hose assemblies with braided stainless steel wire covering.

Robbins & Myers, Inc., Springfield, Ohio has developed a series of re-rated fan cooled motors said to be completely protected against moisture, dust and corrosive atmospheres. They are available in sizes from ½ to 40 hp.

Stainless Steel balls up to 11½ inches in diameter are used in joints at the top and bottom of support columns in bridges designed by three engineering firms, including Harry A. Balke, 2330 Victory Parkway, Cincinnati.

Linde Air Products Div., Union Carbide & Carbon Corp. has new installations under construction or soon to be started which will almost double oxygen producing facilities of the nation. About 30 installations increasing production by nearly 2 billion cubic feet monthly have been constructed or contracted for.

NEW PRODUCTS

(Continued From Page 100)

Electrical energy generated by atomic-powered plants is expected to give Western Europe means of resisting Communism's penetration and is expected to prevent power costs from stifling economic growth of the United States, according to Don G. Mitchell, Sylvania Electric Products, Inc.

G. I. Russell & Co., Ltd., Toronto, Canada has been organized in two divisions, the Pipeline Engineering and Construction Division and the Corrosion Control Division. The latter is under supervision of James R. Wad-dell, formerly with Michigan Consolidated Gas Co. and Union Gas Co. of Canada, Ltd.

Gulf Oil Company's petro-engineering service, offered cost-free to the company's customers, is designed to make available to them the latest discoveries by the company's 1300 scientists, engineers, metallurgists and chemists. These discoveries include use of petroleum rust preventives.

Reynolds Metals Co., 2500 South Third St., Louisville, Ky. will send on request its "Corrosion Keys for Aluminum," a 6-page folder graphically showing corrosion rates of aluminum in varying concentrations of corrosives and common industrial liquids and semi-liquids, including some foods. No data are given on temperatures, pressures or velocities.

Zirconium, reactor grade and commercial grade is supplied by U. S. Industrial Chemical Co., in the form of platelets, irregular flakelike pieces about the size of dimes and quarters. This form is superior to ordinary sponge, is classed as metal, and is, therefore, safe to handle.

Stainless Steel and gray tinted glass will be used on curtain walls of a 52-story office building to be erected on the block between Madison Avenue and Park Avenue, from 47th to 48th streets in New York City. The building will house the home offices of Union Carbide and Carbon Corp. and some of the space will be available for lease. The building is expected to accommodate about 5000 people. Completion is projected early in 1960.

"More Zr Facts," a bi-monthly periodical published by Carborundum Metals Co., Akron, N. Y. will be devoted to technical data on zirconium. First issue is devoted to historical data and features a story on zirconium production. Corrosion resistance of the metal will be featured in future issues, among other things. Copies are available on request.

Analytical Grade ion-exchange resins are described in a folder which lists available resins and gives a selected bibliography of technical writings on ion exchange research. Copies are available from Bio-Rad Laboratories, 800 Delaware St., Berkeley, Cal.

Beckman Instruments, Inc. Scientific Instruments Division plans to add 100,-000 feet of space to its present Fullerton, California plant as a research and development building.

Wilbur & Williams Co., 130 Lincoln St., Boston 35, Mass. has issued a folder titled "Solve These Maintenance Problems of the Food and Chemical Industries with W & W Specialized Coatings." It lists products designed for specialized applications in these fields.

Hagan Chemicals and Controls, Inc. opened its new Rockwood, Mich. processing and packaging plant February 7.

Protectoseal Company, 1920 S. Western Ave., Chicago 8, Ill. has developed a device which permits keeping the nozzle tip of a paint spray gun submerged in a solvent solution to keep paint from hardening on it. Similar receivers are made to which ends of paint spray hoses may be attached to prevent paint hardening at the quick-connector ends when they are not in use.

Griscom-Russell Co., Massillon, Ohio has established a marine testing laboratory at the Harbor Island, N. C. station of The International Nickel Co. It is designed to obtain data on heat transfer and evaporator equipment under service conditions and is expected to help the company in search for more efficient distillation equipment for use in a recently awarded research and development contract with Department of the Interior in the application of low-thermal-difference distillation.

MEN in the NEWS

Christopher P. Blakeley has been appointed chemical products engineer in the boiler chemical sales department of Hagan Chemicals & Controls, Inc., Pittsburgh.

Joe R. Robinson has been appointed manager of Middle West Coating & Supply, Tulsa, Okla. Formerly with Panhandle Eastern Pipe Line Co., Kansas City and Pittsburgh Coke & Chemical Co. He has been with Middle West since 1951. He is a NACE member.

John W. Cosier has been named chief product engineer of The Pfaudler Co., Rochester, N. Y.

Kenneth Fowler has been appointed northwest field representative for Perrault Equipment Corp., Tulsa. His experience with pipe lines dates to 1931.

Melvin W. Aarons has joined the technical staff of Bjorksten Research Laboratories, Inc. as senior physicist in the solid state physics section.

George C. Stineback has been made director of sales of the Chicago Division of the Kendall Co. He formerly was general sales manager of Polyken Industrial Tapes.

E. B. Thompson has been promoted to the post of general sales manager of Parker Rust Proof Co.

Harry A. Fedderson has been made technical director of Loven Chemical of California.

Robert P. "Bob" White has been appointed vice-president in charge of the H. C. Price Co., Pipe Coating Division, succeeding **J. Stewart Dewar**, whose retirement took place December 31. Mr. White has been manager of the firm's pipe coating division since 1951.

Niles C. Bartholomew, general manager of Carborundum Metals Co. has been made a vice-president of the parent company.

Earl Erich has been named sales manager of Tube Turns Plastics, Inc. Louisville, Ky. A graduate of Muehlenberg College, he joined Tube Turns in January, 1955 and in May of that year was placed in charge of sales programs on the West Coast and in the Southwest. He was made assistant sales manager in January, 1956. He is a member of NACE, Society of Plastics Industry, American Chemical Society and American Welding Society.

William B. Thomas has been named manager of Kaiser Aluminum & Chemical Corporation's extrusion plant at Dolton, Ill. He joined Kaiser in 1946.

Ralph Bloom, Jr. has been given the newly created position of technical coordinator at Becco Chemical Div., Food Machinery and Chemical Corp., Buffalo.

Aaron Misrock is new engineering sales representative of Water Service Laboratories, Inc. in the Richmond, Va. area. His office will be at 728 East Main St.

MEN in the NEWS

(Continued From Page 103)

Charles F. McMackin has been made superintendent of the Portland, Oregon plant of Stauffer Chemical Co. He joined Stauffer in 1943 as a control chemist. **John B. Gay,** formerly manager of the Portland plant has been made manager of the company's Vernon, Cal. plant.

•

Harrison M. Love, Jr. will assist the Atlanta regional sales manager of Royston Laboratories, Inc. in the Southeastern states.

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Elwood D. Mairs has been selected as the recipient of the 1957 David Ford McFarland Award for Achievement in Metallurgy by the Penn State Chapter of the American Society for Metals. He is works manager for Alcoa's Lafayette, Ind. tubing and extrusion plant.

Norman D. Groves, has been named to direct the expanded corrosion research laboratory of The Carpenter Steel Co., Reading, Pa. and the overall corrosion research activity of the company. Recently corrosion engineer at the Hanford Atomic Products Operation at Richland, Wash., Mr. Groves will have charge of Carpenter's expanded inquiries into corrosion problems associated with atomic energy applications. He is a member of NACE technical committees and the American Society for Metals.

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Donald I. Bohn, Alcoa manager of special electrical development since 1953 retired January 1 after 34 years with the company. He is widely known in the electrical and power generation field as a designer, inventor and engineer.

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Bert S. Nelson is new director of engineering for the Products Division of Hills-McCanna Company, 3025 N. Western Ave., Chicago, Ill. He lives at Hinsdale, Ill.

•

Lee L. Davenport is scheduled to be president of Sylvania-Corning Nuclear Corp. when it is formed soon.

•

Henry Ott, formerly principal metallurgist in Battelle Institute's Alloys Development Division will work on problems associated with the corrosion of metals on the metallurgy staff of Denver Research Institute, University of Denver.

•

Joseph J. Tapas has joined the market development department of Industrial Chemicals Division, Olin Mathieson Chemical Corp., Baltimore.

CORROSION ENGINEERING DIRECTORY

CORROSION ABSTRACTS

INDEX TO CORROSION ABSTRACTS

3. CHARACTERISTIC CORROSION PHENOMENA

3.6 Electrochemical Effects

3.6.5, 3.8.2, 3.5.9

The Temperature Effect in Half-Cells. M. BONNEMAY. Proc. 6th Meeting Internat. Cttee. Electrochem. Thermodynamics and Kinetics (Poitiers, 1954), 1955, 68-76; disc., 77-78.

Two similar electrodes immersed in two similar solutions but at different temperatures were arranged in opposition. With a hydrogen electrode, measurements were made in hydrochloric acid (with additions of sodium sulfate, magnesium chloride, barium chloride and sodium chloride), sulfuric acid (with addition of sodium sulfate) and phosphoric acid. With cadmium, measurements were made in cadmium sulfate, cadmium nitrate + sulfuric acid, and cadmium chloride + sulfuric acid; with zinc, in zinc sulfate; with copper, in cupric nitrate + sulfuric acid and cupric sulfate + sodium sulfate. If $\gamma_m =$ voltage/temperature difference,

$\gamma_m = \gamma_0 + (R/nF) \ln a$, where $R =$ gas constant, and $n =$ valency and $a =$ activity of the reacting ion. The values found for γ_0 (mV./°C.) are: H/Pt, 0.65; amalgam of saturated cadmium, 0.3; cadmium, 0.456; zinc or 10% zinc amalgam, 1; copper or 10% copper amalgam, 0.81. The results are believed to be correct to ~5%. Reasons are adduced for believing that the liquid junction exerts a negligible effect on the measurements. The figure obtained is independent of the nature of the anion. —MA.   11715

3.6.8, 3.7.4, 3.8.2

Fundamental Studies on Corrosion of Alloys. Rept. VI Relation Between the Hydrogen Overvoltage and the Lattice Constant of Alloys. N. OHTANI. *J. Japan Inst. Metals,* 20, No. 3, 158-162 (1956) March.

Concerning various metals with body-centered cubic, face-centered cubic and close-packed hexagonal lattices, the author investigated how the bond energy W and the adsorption energy U of atomic hydrogen showed a maximum value at the distance of the nearest neighbor atoms $\gamma \cong 2.7$ A. Then assuming the relationship between the bond energies and the lattice constants of those metals, the author also derived an experimental formula, in which the hydrogen overvoltage showed a minimum value at $\gamma \cong 2.7$ A, to calculate the values of the hydrogen overvoltage of various metals and alloys.—JSPS.   12541

3.6.8, 3.7.4, 3.8.2

Fundamental Studies on Corrosion of Alloys. Rept. VII. The Hydrogen Overvoltage and the Bond Energy of ε-Phase.

N. OHTANI. *J. Japan Inst. Metals*, **20**, No. 3, 162-165 (1956) March.

The author calculated approximately the value of the bond energy of the ε-phase, an electron compound with close-packed hexagonal lattices, attributing the extremely small value of the hydrogen overvoltage of the ε-phase to the adsorption energy of atomic hydrogen and therefore the bond energy of metals at the lattice constant $\alpha = 2.7$ A. Then deriving the relation among the first term of Tafel's equation connected with the electrode metal, the bond energy of metal and the lattice constant α, the author showed the possibility of deciding the general tendency of the variation of the hydrogen overvoltage against changes in the composition of many alloys.—JSPS.   12543

3.6.9, 7.7, 5.2.1

Two Cases of Corrosion in Suburban New York Disguised as Galvanic—Their Cause and Mitigation. W. SEARLE WOODWARD. *Corrosion*, **12**, No. 9, 427t-432t (1956) September.

Two cases are reported in which stray current potentials were mistaken for galvanic potentials from underground lead-sheathed telephone cables to ground. Lack of suitable meters prevented assessment of the true potentials of the cables which suffered severe corrosion damage.

Case 1 pertains to relatively high stray current area adjacent to both the New York City subway system and the electrified New York Central Railroad. First tests showed steady positive potentials similar to those which might result from a galvanic source. When the fixed potential was blocked out by an opposite fixed potential, a marked fluctuation of potentials to earth was observed. Bonding reduced the cable-to-earth potential to a range of —0.1 to —0.4 volt.

Case 2 pertains to a section of cable where an average of 8.9 failures per 100 sheath miles per year occurred over an extended period of time. The damage began to occur shortly after discontinuance of a trolley system. A rectifier-powered cathodic protection system, installed in 1940, improved conditions on

all but about 4,000 feet of the cable. Later, tests indicated alternating currents from the 11,000-volt, 25-cycle return of the New York, New Haven and Hartford main line were somehow related to direct currents on the sheaths; surges being correlated to railroad operation. The author postulates that the direct current may have been the result of the rectification of several AC potentials of different magnitudes over a large area. Corrections attempted by bonding a half-wave selenium rectifier to the adjacent railroad structure were successful, but a series of rectifier breakdowns, due to surges, was experienced. The use of a rectifier embodying a protective circuit eliminated breakdowns, but additional testing and corrections are being made to bring the whole section to a potential which will reduce corrosion.
12207

3.7 Metallurgical Effects

3.7.3

How to Use Fluxes and Solders for Good Joints. W. P. McQUILLAN. Westinghouse Elec. Corp. *Am. Machinist*, **100**, No. 1, 81-84 (1956) January 2.

Includes corrosive vs non-corrosive fluxes, composition of solder alloys, effects of residual flux, techniques for removing flux, melting points for progressive assembly, joint strength vs temperature and electrical resistance of joints. Phase diagrams for lead-tin solders are shown. Graphs, photomicrographs.—INCO.   11366

3.7.3

The Effect of Cold Working on Changes in Properties of Metals and Alloys. Part I. Variation of Hardness and Tensile Strength by Cold Working. E. DONNGES. *Z. Metallkunde*, **46**, 867-872 (1955) Dec.

Effect of cold-working on hardness and tensile strength of metals with cubic structure was investigated. Curves of hardness and tensile strength as function of degree of deformation do not rise continuously. Explanation of effects observed is

given. Tests were on nickel, nickel silver, gold, copper and silver.—INCO.   11462

3.7.3

Lithium Additions to Brazing Alloys. N. BREDZS AND D. CANONICO. *Welding J.*, **34**, No. 11, 535s-543s (1955) Nov.

Results indicate lithium to be suitable for development of self-fluxing brazing alloys: lithium-bearing silver alloys and lithium-bearing copper alloys should prove useful for brazing plain-carbon and stainless steels, without flux or reducing atmospheres.—BNF.   11 20

3.7.3, 1.6

Brazing Manual. Book, 1955, 193 pp. Prepared by Committee on Brazing and Soldering, American Welding Society. Reinhold Publ. Corp., New York.

Principles, equipment and procedures involved in all eight brazing processes, every operation from pre-cleaning and surface preparation to postbraze cleaning and inspection and techniques of brazing aluminum, magnesium, copper, steels, iron, nickel and many other metals are among the many topics discussed.—INCO.   11323

3.7.3, 6.4.2

Soldered Joints in Aluminium : Mechanism of Corrosion. W. J. SMELLIE. *Light Metals* (England), **19**, No. 220, 210-214 (1956) July.

Immersion tests in tap water at 100 C and 3% salt solution at room temperature have been carried out on soldered joints in aluminum using tin, lead, cadmium, zinc and alloys based on these metals as solders. Results indicate that electrochemical interface failure is to be expected on joints made from solders consisting of tin, lead and cadmium. This failure is relatively quick. Zinc base solders free from harmful metals undergo slow attack on the solder body and are to be preferred where a wide range of service conditions is anticipated. (auth)—ALL.   12600

3.8 Miscellaneous Principles

3.8.2

Aeration Cells. (In German.) HERIBERT GRUBITSCH. *Monatsh. Chemie*, **86**, No. 5, 752-764 (1955) October.

Iron corrosion in a neutral aerated electrolyte solution as a pure diffusion controlled process. Tables, graphs, diagram. 37 references.—BTR.   11798

3.8.2

Electrochemical Nomenclature and Definitions. PIERRE VAN RYSSELBERGHE. Proc. 6th Meeting Internat. Cttee. Electrochem. Thermodynamics and Kinetics (Poitiers, 1954), 1955, 20-47; disc., 48-49.

A report by a commission of which van Rysselberghe is chairman. Among the comprehensive list of definitions the following may be noted. The electrochemical free energy of a one-phase system is defined as the energy diminished by temperature x entropy. The electrochemical free enthalpy is the electrochemical free energy +(pressure x volume). The term "electrochemical double layer" is used instead of "electrical double layer." The unit of advancement of a reaction is called a "dedonder," so that affinities and heats of reaction are expressed in cal./dedonder. In a galvanic cell, reversible electrical potential difference = electromotive force. Noble electrode potential differences are positive.
—MA.   11807

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3.8.2

The Specific Adsorption of Ions at the Metal/Electrolyte Interphase. ROGER PARSONS. *Trans. Faraday Soc.*, **51**, No. 11, 1518-1528 (1955).

Thermodynamic equations for the surface excess at constant surface charge are derived. In integrating these, it is assumed that a charged polarizable metal plate is in contact with a solution containing cations and anions of the same valency in a structureless solvent and the double layer in the solution consists of a monolayer containing specifically adsorbed anions and a diffuse double layer containing both anions and cations. Direct comparison of the effective surface pressure of I⁻ films on mercury is made with seven types of isotherm. Agreement is found with an isotherm based on either a virial equation of state with a square-root term or the Amagat equation and it is suggested that these

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permit the separation of interactions within the film from those of the film with the metal surface. There is no definite preference for either equation; the former gives a slightly better fit with the experimental points, but the constants of the Amagat equation can be more readily interpreted. 25 references. —MA. 11911

3.8.2, 6.3.19, 5.3.4

Electrochemical Behaviour of Monocrystalline Surfaces: Deposit and Electrochemical Attack on the (0001) Face of Pure Zinc. L. CAVALLARO AND G. P. BOLOGNESI. *Rev. Met.*, **52**, No. 9, 706-710; disc., 710 (1955).

Electrochemical attack can be considered as the inverse of electrodeposition and in both cases the best results are obtained by using a perfect surface, such as a freshly cleaved surface. Experiments were therefore made on the (0001) face of a single crystal of zinc, which is very easily cleaved. The bath consisted of: $ZnSO_4 \cdot 7H_2O$ 450, orthoboric acid 30 g/l., pH = 3.5. The current density was found to have a considerable effect on the microscopic appearance of the deposit: at 1 amp./dm.² isolated hexagons were observed, but at 5 amp./dm.² the specimen was completely covered. At 20 amp./dm.² the surface was macroscopically very irregular. The effect of various inhibitors was investigated; these usually affected the adherence and brilliance of the deposit. The results were compared with those obtained, under the same conditions, by anodic attack; and certain parallels in the phenomena were observed. 8 references.—MA. 11787

3.8.2

Our Contemporary Conception of Electrochemical Mechanism of Corrosion. Pt. I. (In German.) W. SCHWARZ. *Metall*, **10**, No. 11/12, 513-519 (1956) June.

Discusses chemical and electrochemical corrosion; physical and chemical effects; hydrogen and oxygen corrosion. Diagrams, graphs. 5 refs.—BTR. 12590

3.8.2, 3.4.8

Effects of Metal Cations on the Corrosion of Iron in Acids. HARRY C. GATOS. *Corrosion*, **12**, No. 7, 322t-330t (1956) July.

The corrosion of iron was studied in 1N sulfuric acid, 1N hydrochloric acid and 1N acetic acid containing oxidizing, reducing, or stable metal cations. Oxidizing cations (Fe^{+++}, Ce^{++++}, Cu^{++} and $Cr_2O_7^{--}$) increased the corrosion rate of iron in these acids. The increased rate was found to be a linear function of the cation concentration for the concentration range studied (up to 0.1 g ions/liter). For the same oxidation-equivalent concentration the corrosion rate was proportional to the valence change which the metal cations underwent during the corrosion process. Reducing cations (As^{+++} and Sn^{++}) decreased considerably the corrosion of iron in acids, whereas stable cations (Fe^{++}, Mn^{++}, Cr^{+++} and Ni^{++}) with the exception of Ni^{++} showed no effect.

The electrochemical action of the various cations was explained on the basis of corrosion data and electrode potential measurements. 12443

3.8.2, 3.4.9

A Study of Metal Corrosion with the Aid of the Heavy Oxygen Isotope. Part I. Moist Atmosphere Corrosion of Iron.

(In Russian.) A. I. BRODSKII, A. S. FOMENKO AND T. M. ABRAMOVA. *J. Phys. Chem., USSR* (Zhur. Fiz. Khim.), **30**, No. 3, 676-684 (1956) March.

Role of electrochemical and chemical mechanisms in the moisture corrosion of iron. Graphs, tables, diagram. 15 references.—BTR. 12346

3.8.2, 6.3.21

Electrochemical Behavior of Tellurium. Diagrams of the Equilibrium Tension-pH of System Te/H₂O at 25°C. (In French.) April, 1956, 26 pp. E. DELTOMBE, N. deZOUBOV AND M. POURBAIX. Centre Belge d'Etude de la Corrosion, 21 Rue des Drapiers, Bruxelles, Belgium.

The study gives free enthalpies of standard formation at 25 C, reactions and equilibrium formulae and diagrams of equilibrium tension-pH and interpretation. There is a bibliography of 47 references and three figures. 12390

3.8.4, 6.3.6, 3.7.4

The Rates of Oxidation of Several Faces of a Single Crystal of Copper as Determined with Elliptically Polarized Light. F. W. YOUNG, JR., J. V. CATHCART AND A. T. GWATHMEY. *Acta Metallurgica*, **4**, No. 2, 145-152 (1956) March.

Rates of oxidation of the (100), (111), (110) and (311) faces of a copper single crystal were determined at the temperatures 70, 106, 130, 159 and 178 C by measuring the increase in thickness of the oxide film as a function of time. A polarizing spectrometer was used to measure film-thickness. Particular emphasis was placed on preparing a smooth, clean, strain-free surface of known orientation. Relative order of the rates of oxidation of these faces was found to be (100), (111), (110), (311) in decreasing order. Results showed the great difference in the rate of oxidation with crystal face at these temperatures, the ratio of the thickness of the oxide on the (100) face to that on the (311) face being 12.5 for oxidation at 178 C. An analysis of the results, according to the present theories of the oxidation of metals, was presented. Illustrations.— INCO. 12197

4. CORROSIVE ENVIRONMENTS

4.3 Chemicals, Inorganic

4.3.2

Materials for Storage of Sulfuric Acid. (In Serbian.) E. RABALD. *Zastita Materijala*, **4**, No. 6, 193-197 (1956) June.

The corrosive effect of sulfuric acid on various types of steels and alloys under different conditions.—BTR. 12556

4.3.2, 6.2.1

The Rates of Dissolution of Iron and Iron-Chromium Alloys in Nitric Acid. (In French.) T. G. ÔWE BERG. *J. Chim. Phys.*, **54**, No. 2, 163-168 (1956) Feb.

The rates of dissolution in nitric acid of soft steel and iron-chromium alloys were measured between 0.25 N and 10 N. The soft steel and alloys with ½, 1 and 2% chromium dissolve like Armco iron, the adsorption of the reagents governing the rate. For the other alloys, the rate of dissolution is proportional to the square root of the acid concentration. Tables, graphs. 2 references.—MR. 12376

4.3.2, 6.3.10

The Rate of Dissolution of Nickel in

Nitric Acid. (In French.) T. G. OWE BERG. *J. Chim. Phys.*, **54**, No. 2, 154-162 (1956) Feb.

Rate was measured from 0 to 65 C for concentrations between 0.025 N and 14.5 N. Below 3.5 N, the rate of dissolution is proportional to the square root of the concentration. Above 9 N, the results are very complex and difficult to reproduce. Tables, graphs. 3 references.—MR. 12374

4.3.2, 6.4.2
Aluminum Versus Fuming Nitric Acids. R. L. HORST. (A Report by NACE Task Group T-5A-5 on Corrosion by Nitric Acid. J. L. English, Chairman.) *Corrosion*, **12**, No. 10, 77 (1956) Oct.

Tests on welded aluminum alloys with boiling 98 percent nitric acid show uninhibited white and red fuming acid attacks both base metal and zones adjacent to welds. At 160 F white, nitric acid attacked several welded specimens, all at the weld. At 122 F uniform corrosion under 20 mpy was noted with no corrosion at or adjacent to welds. Up to 122 F red fuming nitric acid is commonly handled in several alloys, while above this temperature knife-line attack adjacent to welds was noted on all specimens except 1060 welded with 1060 which showed mild etch: As little as 0.1 percent hydrofluoric acid inhibited red fuming nitric acid at 160 F, with 6061 welded with 4043 showing negligible attack after four weeks. Inert gas methods are preferred over others to prevent corrosion associated with flux. 12348

4.3.3, 3.7.3, 5.3.2
Corrosion in Caustic of Nickel-Iron Welds Obtained in Fabrication of Nickel-Clad Vessels: Topic of the Month. PAUL J. GEGNER. *Corrosion*, **12**, No. 6, 261t-262t (1956) June.

Tests indicate that in nickel-clad vessels for sodium hydroxide, iron can be tolerated in the welds up to about 25% in respect of corrosion. Additional work is planned to evaluate susceptibility to stress cracking. The above figure is higher than has heretofore been permitted in most American specifications.—BNF. 12460

4.3.4, 8.3.1
Corrosion of Metals by Liquid Fertilizer Solutions. D. C. VREELAND AND S. H. KALIN. *Corrosion*, **12**, No. 11, 569t-575t (1956) November.

Laboratory corrosion tests were conducted on aluminum, carbon steel, chromium and chromium-nickel stainless steels to evaluate their suitability as constructional materials for storage, transport and applicator tanks for "nitrogen" and "complete-mix" liquid fertilizers. Two types of corrosion tests were conducted: 1) Partial immersion of small specimens of each material in each fertilizer solution, and 2) Simulated service tests in which small tanks fabricated of each of the test materials were partially filled with each of the fertilizer solutions. The amount and type of corrosion was evaluated by weight-loss determinations, thickness changes, pit-depth measurements and metallographic examinations.

The results of the corrosion tests showed that in the nitrogen fertilizer solutions aluminum and several chromium and chromium-nickel stainless steels were not attacked while carbon steel was attacked. In the complete-mix fertilizer solutions, only the chromium-nickel stainless steels were not attacked while aluminum carbon steel and three chromium stainless steels were attacked.

Service tests are being considered on carbon steel and some of the stainless steels that had satisfactory corrosion resistance in the laboratory tests. 12449

4.3.5
Development of Shipping Cylinders for C-216 (Fluorine). Problem Report JWD-43. J. F. FRONING AND M. K. RICHARDS. Du Pont de Nemours (E. I.) and Co. U. S. Atomic Energy Comm. Pubn., A-2555, January 20, 1945 (Declassified January 18, 1956), 13 pp. Available from: Office of Technical Services, Washington, D. C.

Nickel and steel cylinders were evaluated for use in shipping fluorine under pressure. Data are summarized.—NSA. 12456

4.3.6, 5.8.2
Protecting Ammonium Sulphate Crystallizers by Means of Inhibitors. G. ROBERTI, et al. *Metallurgia Italiana*, **48**, 281-286 (1956) June.

Corrosion of 18/8 and 18/8/3 molybdenum steels in ammonium sulfate crystallizers is inhibited by copper sulfate, potassium dichromate, hydrogen peroxide and sodium arsenite (about 100 ppm).—INCO. 12572

4.3.6, 6.2.3
Contribution to the Study of Corrosion of Steel in Saline Solutions. (In French.) A. HACHE. *Rev. Met.*, **53**, No. 1, 76-79; disc., 80 (1956) Jan.

The influence of temperature and salinity were studied according to the dissolved oxygen existing in the saline solutions. Diagram, graphs, table. 4 references.—BTR. 12462

4.3.4, 8.3.1
Liquid Fertilizers. L. REZNEK. *Petro-*
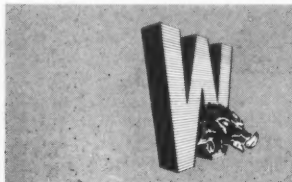
leum Transporter, **17,** No. 3, 6-9, 28 (1955) Jan.-Feb.

Discusses opportunities and problems for tank truck owners in transportation, distribution and application of liquid fertilizers. Fertilizers adaptable to tank truck transportation are divided into four general categories: anhydrous ammonia, aqueous ammonia, nitrogen fertilizer solutions, and lawn-spray type solutions. Basic requirements for tank trucks to be used to transport these four types of fertilizers are tabulated. Tank materials include common steel, aluminum and stainless steel. Since anhydrous ammonia rapidly corrodes copper and copper-bearing alloys, all valves, piping and any other accessories in contact with materials must be steel.—INCO.   11727

4.3.4, 8.3.1, 6.2.3

The Corrosion of Steels in Relation to Fertiliser Chemicals. C. R. PIPE. *Fertiliser Society Proceedings.* (England.) No. 32, 31-47; disc., 48-49 (1955).

The corrosion of steels with special reference to fertilizer chemicals. In considering the types of steel available, reference is made to the economic factors related to their production. Photograph, diagram, micrographs, tables, graph. 15 references.—MR.   11728

4.3.4, 8.3.1

The Chemistry and Metallurgy of Corrosion of Metals by Fertiliser Materials. W. D. CLARK. *Fertiliser Society Proceedings* (England.) No. 32, 4-22; disc., p. 22-23 (1955).

Theory of corrosion processes, resistance of metals to corrosion, corrosive properties of fertilizers. Tables, diagrams, photographs.—MR.   11828

4.3.5, 3.4.8

The Chemical Action of Chlorine and Its Compounds on Metals and Metallic Oxides. (In Polish.) WLADYSLAW DOMANSKI, *Archiwum Gornictwa i Hutnictwa,* 3, No. 3, 401-435 (1955).

The method of calculation of the chemical affinity of metals for chlorine gas as a function of temperature has been illustrated in its application to the analysis of the Betterton process. Results were confirmed by the data of metallurgical practice. Graphs, tables. 11 references.—BTR.   11918

4.4 Chemicals, Organic

4.4.3, 4.4.7

Corrosion of Selected Materials in Pentalene 290 and a Mixture of Dowtherm A and Alkylbenzene. WALTER K. BOYD AND ROBERT S. PEOPLES. Battelle Memorial Institute. U. S. Atomic Energy Commission Pubn., BIM-1046, October, 1955, 9 pp.

Aluminum 52S and 61S, coupled and uncoupled samples of Armco 17-7PH, Type 316 stainless steel, Hastelloy X, Croloy 5, Alfenol (15.5Al), zirconium-5wt.% tin, Zircoloy 2 and beryllium were tested. Pentalene 290 decomposes rapidly at temperatures of 600 F and above. Diagram, tables, photographs.—BTR.   11830

4.4.7, 5.8.2

Rust Inhibitors in Lubricating Oils for Periodically Operated Working Machines. (In Russian.) B. V. LOSIKOV AND L. A. ALEKSANDROVA. *Vestnik Mashinostroeniia,* **36,** No. 5, 12-15 (1956) May.

An experimental study of a number of rust-preventing additives for lubricating

oils. Efficacy of the additives depends on the shape and positions of parts lubricated. Photographs, tables. 10 references.—BTR.
12496

4.4.7, 5.8.2

The Chemistry of Lubrication-Oil Additives. ARNOLD MILLER. *J. Chemical Education,* **33,** 308-312 (1956) July.

Antioxidants; lubricity and extreme-pressure additives; pour-point depressants; viscosity index improvers; rust inhibitors. Photographs, graph. 22 references—BTR.
12530

4.5 Soil

4.5.1

Specific Resistance (Electric) of the Soil. (In Dutch.) J. W. BOON. Publication 43, July, 1956, 58 pp. Metaalinstituut TNO, Afdeling Corrosie, Delft, Holland.

Methods of measuring soil resistance are outlined and instruments discussed. Chapter five explains the relation between the average specific resistance of ground and its corrosivity. A 50-page book giving specific field data on resistance measurements of soil in Holland is included. 12425

4.5.1

The Role of the Dispersed Soil Phase in Underground Iron Corrosion. (In German.) T. MARKOVIC, B. JAZBEC AND N. PLAVSIC. *Werkstoffe u. Korrosion,* 7, No. 7, 385-390 (1956) July.

Effect of dispersed soil particles in the water layer on the corrosion of iron. Oxygen distribution in the liquid column of dispersed alumina particles.—BTR. 12548

4.5.3

Magnetic Amplifier Type Recording Instrument for Electrolysis Survey. MICHIO TANAKA, JIRO YAMAGUCHI AND YOSHIFUMI SAKURAI. *Corrosion,* 12, No. 11, 549t-552t (1956) November.

In order to make plans for corrosion control of underground metallic structures it is necessary to survey the sheath current and potential against the ground. A current and voltage recording instrument which was designed for making an electrolysis survey is described and field test results are reported. The instrument consists of a push-pull self-saturation type magnetic amplifier and a conventional electrical recording voltmeter. It was found to perform as follows:

1. For obtaining 0.6 volt (this corresponds to the full scale 50 mm in the recording meter used) input voltage of the amplifier with Mo-Permalloy cores was 0.48 millivolt for sheath current measurement and 740 millivolts for cable to ground potential measurement in case of the power source of 90 cps with rectangular wave form.

2. Response time was 7 cycles for current measurement and 4.5 cycles for voltage measurement.

3. When the source was supplied from the power line (60 cps), the amplification factors decreased about 10 to 35 percent.

The device had good stability, negligible drift and rugged construction. Therefore it is clear that this device is suitable for field test. 12453

4.6 Water and Steam

4.6.1, 5.8.2, 3.3.4

What to Do When Water Changes Its Mind. F. S. HODGDON. *Heating, Piping, Air Conditioning,* 28, 97-102 (1956) June.

Water conditioning program includes proportional feeding of complex phos-

phates to makeup water, with bleedoff, to prevent scaling; addition of phosphates, nitrites, or chromates to the cooling tower water to prevent corrosion; and use of chlorine gas, sodium hypochlorite, or chlorinated phenols for algae and slime. Table, graphs, diagrams.—BTR. 12438

4.6.2

Corrosion in Steam and Condensate Lines. Causes and Prevention. (In French.) J. PIERREY. *Corrosion et Anticorrosion,* 4, No. 5, 225-230 (1956) June.

Corrosion caused by oxygen and especially carbonic acid plus moisture. Various methods for removing carbonates and bicarbonates from the water. Use of volatile amines and of film forming amines as neutralizers.—BTR. 12538

4.6.2

Metallurgical Requirements of Metals for Steam Service Above 1000 F. F. B. FOLEY AND R. M. WILSON, JR. Paper before Am. Power Conf., Ann. Mtg., Chicago, March 21-23, 1956. *Blast Furnace Steel Plant,* 44, No. 5, 508-512 (1956) May.

Covers high temperature tensile properties and design stresses, oxidation and corrosion resistance, stability, thermal expansion, fabrication and welding and cost of alloys for steam service at 1000 F and over. Methods for determining design stresses based on ASME Power and Pressure Vessel Code are discussed. Stabilization by nickel of austenite and prevention of sigma or chi formation are considered and sigma phase diagrams are shown. Data are presented for 2.25 chromium-1 molybdenum steel, Types 347 and 316 and 2 experimental alloys—15-15-N (14.75-18.00 chromium, 13.5-16.5 nickel, 1.25-1.85 molybdenum, 1.00-1.85 tungsten and 1.30 niobium + tantalum) and G-18B (13 chromium-13 nickel 2 molybdenum-2.5 tungsten-3.0 niobium + tantalum-10.0 cobalt). Tables graphs.—INCO. 12433

4.6.2, 7.6.4, 7.4.2, 2.2.1

Field Studies of Pre-Boiler Corrosion in High Pressure Steam Plants. H. A. GRABOWSKI, H. D. ONGMAN AND W. B. WILLSEY. Paper before Am. Power Conf., 18th Ann. Mtg., Chicago, March 21-22, 1956. *Combustion,* 27, No. 11, 46-51 (1956) May.

Submits test results and experiences encountered in collecting data for valid evaluation of degree of corrosion existing in pre-boiler circuits of 21 utility unit boiler-turbine combinations. Manner and frequency of analyzing spot samples and location of test points are considered. Effect of deaeration on corrosion rate was evaluated in systems employing condenser hot well deaeration and systems using direct contact deaerating heaters. Chemical control of pH by use of morpholine, cyclo-hexylamine, ammonia or hydrazine is insufficient if large quantities of carbon dioxide or sulfur dioxide are introduced into cycle. Ammonia, in pH range 8.5-9.5, reduced copper corrosion considerably. Table, graph. —INCO. 12439

4.6.2, 7.6.4, 3.8.2

The Reactions Between Solid Cupric Oxide and Iron or Fe₃O₄ and the Effect of Oxygen or Water Vapour. (In German.) K. WICKERT AND H. WIEHR. *Werkstoffe u. Korrosion,* 7, No. 1, 13-16 (1956) Jan.

Deposits in the tubes of high pressure boilers contain more or less copper and its oxides. Originally, cupric oxide is deposited from water or vapor. It reacts with Fe_3O_4 and with iron to form copper.—BNF. 12192

4.6.11, 2.2.7, 6.4.2

Corrosion of Aluminium Structural Parts of a German Escort Vessel Sunk During the War. (In German.) F. E. FALLER. *Aluminium,* 32, No. 3, 136-138 (1956) March.

Investigation of the effect of sea water on the aluminum alloy wheelhouse, superstructure and roof, top bulwark, etc., of a German escort vessel, "Konigin Luise", salvaged after 7 years' total immersion, the vessel having been sunk in Wilhelmshafen by bombing. Alloys used were aluminum-copper-magnesium aluminum-clad sheet, with AlMg7 rivets and aluminum-silicon casting alloy window frames. All parts of commercially pure aluminum, anodized or painted aluminum or aluminum alloy except the AlMg7 rivets (now no longer used) showed little or no corrosion. Results of some tensile tests are also given.—BNF. 12457

4.7, 5.3.2

Stainless Steel Coatings to Prevent the Corrosion of Copper. L. O. LOVE AND W. K. PRATER. Oak Ridge National Lab., Y-12 Area, Tenn. U. S. Atomic Energy Comm. Pubn., Y-703, January 12, 1951 (Declassified January 5, 1956), 8 pp. Available from: Office of Technical Services, Washington, D. C.

In separating the stable isotopes of lithium in the calutron, lithium metal was investigated as a possible charge material. First results indicated that the corrosive action of the hot lithium metal, especially on the copper castings of the source unit, would preclude its use unless some method of protecting the castings could be found. The noncorrosive properties of iron suggested the possibility of coating those source parts affected by the lithium metal with non-magnetic stainless steel. This was tried in the following manner: The charge oven casting and the arc chamber casting were sand blasted and a coat of stainless steel, approximately 15 inches thick was sprayed on. The effectiveness of this treatment in preventing corrosion of the casting is clearly shown. Out of a total of 100 or more runs in which coated castings were used, no failures occurred due to corrosion of the castings. (auth).—NSA. 12499

4.7, 8.8.5, 5.3.4

Notes on Attack of Zinc on the System Iron-Iron Carbide. (In German.) W. KROOS. *Metalloberflache,* 10, No. 6, 187-188 (1956) June.

Material investigated was 0.18% carbon rolled steel as used both for galvanizing and for making kettles. Describes conditions leading to attack of zinc on ferrite, particularly however on carbide and pearlite. Promotion of attack by increased temperatures, particularly at kettle walls, leading to pitting and ultimately to fracture. Attention is drawn also to the effect of aluminum additions and to the stability of graphite-carbon and temper-carbon in contrast to carbide.—BNF. 12491

4.7 Molten Metals and Fused Compounds

4.7

Attack on Materials by Lead at 1000 C. W. D. WILKINSON, E. W. HOYT AND H. V. RHUDE. Argonne National Lab. U. S. Atomic Energy Comm. Pubn., ANL-5449, October, 1955, 30 pp.

This is the Final Report on Program 8.2.2 and covers work done prior to December 1, 1949.

A method for determining the resist-

ance of materials to attack by lead at 1000 C is described. Results of preliminary tests indicate that sintered beryllia, fused silica, tantalum and probably niobium and a sintered mixture of beryllia and urania have good resistance. SAE-1020 carbon steel, Type 430 stainless steel, chromium, Type 347 stainless steel, Type 302 stainless steel, Inconel, molybdenum, Armco iron, zirconium and titanium, had fair to poor resistance to attack by lead, in decreasing order as listed. Cast iron and uranium underwent complete dissolution. (auth)—NSA.
11895

4.7

Materials and Fabrication. W. L. FLEISCHMANN AND R. F. KOENIG. Paper from "Liquid-Metals Handbook. Sodium (NaK) Supplement," 3rd. Ed., 1955, 159-186. U. S. Atomic Energy Commission and Department of the Navy. Available from Superintendent of Documents, U. S. Government Printing Office, Washington, D. C.

Factors which influence the choice of materials and fabrication methods for a sodium or NaK coolant system. Graphs, micrographs, tables, diagrams, photographs. 38 references.—BTR.   11734

4.7

Corrosion by Liquid Metals. L. F. EPSTEIN. Paper before Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, August, 1955. United Nations Paper A/CONF.8/P/119, July 7, 1955, 22 pp.

For service in mercury, nickel free steels are best. To withstand high temperature as well, Sicromo 5 S (Croloy 5 Si) which contains 5 chromium, 0.5 molybdenum, 1.5 silicon is recommended. In mercury boilers, magnesium is added to the mercury charge as a wetting agent. The addition of 1 to 10 ppm metallic titanium to the mercury inhibits corrosion of ferrous alloys (nickel free) by mercury. This is a patented process. Stainless steel gains weight in sodium due to formation of surface films of chromium oxides. A low carbon steel loses weight continuously in sodium due to decarburizing action of the sodium. With 18/8 stainless penetration rates of 0.1 mil per year (0.0025 mm/year) or less are readily achieved if the oxygen content of the sodium is kept low. In alkaline metals diffusion bonding takes place, between two pieces of solid metal immersed in liquid sodium at an elevated temperature. The liquid serves as a solvent and facilitates the transfer of atoms from one solid to another. Graphite is drastically attacked by sodium. Static and dynamic tests are described.—INCO.
11775

4.7, 1.6

Thermal and Related Physical Properties of Molten Materials. Part II. High Temperature Reaction of Sodium Hydroxide. DALE D. WILLIAMS AND R. R. MILLER. Naval Res. Lab., Washington, D. C. U. S. Wright Air Development Center, Tech. Rept. 54-185 (Pt. II), February, 1955, 64 pp. Project No. 1252; Task Title: Molten Metals.

The reactions between molten sodium hydroxide and nickel and other container materials have been investigated in the temperature range 700 to 900 C. The general equation for the primary reaction occurring is: $NaOH + Metal = Na_2O + Metal$ oxide $+ H_2$. In static systems, nickel may be used as a container for molten sodium hydroxide at temperatures to 1000 C with hydrogen protection.—NSA.
11905

4.7, 1.6

Liquid Metals Handbook: Sodium-NaK Supplement. (Heat Exchange). C. B. JACKSON, Editor. Book, 1955, 445 pp. Available from: Supt. of Documents, Washington, D. C.

A detailed account of all aspects of American experience of the use of molten sodium and NaK for heat exchange purposes, including plant design.—BNF.
11872

5. PREVENTIVE MEASURES

5.1 General

5.1, 1.3, 8.1.4

Suggested Nontechnical Manual on Corrosion for Water Works Operators. LEE B. HERTZBERG. *J. Am. Water Works Assoc.,* **48**, 719-738 (1956) June.

Types of corrosion; costs; insulation; pipe fittings; painting and coating; bonding; cathodic protection; pipeline selection. Diagrams, graphs, tables. 11 references.—BTR.   12446

5.2 Cathodic Protection

5.2.1

Cathodic Protection. (In Dutch.) J. W. BOON. Pubn. No. 42, July, 1956, 1-8. Metaalinstituut T.N.O., Afdeling Corrosie, Delft, Holland.

Covers principles, galvanic methods, anode and cathode reactions, criteria of full protection, secondary effects and practical experience on a pipe line.

5.2.1

Location of Contact Between Cathodically Protected Lines and a Foreign Line. L. F. HEVERLY. *Pipe Line News,* **28**, 49-50, 54 (1956) July.

Contact between a cathodically protected pipe line and a bare water line in a distribution network can destroy the usefulness of a cathodic protection system unless steps are taken to electrically isolate one from the other. Article discusses the procedure used to find the exact location of a contact with a water line underneath a reinforced concrete paved street.—BTR.   12442

5.2.1

Spread of (Cathodic) Protection. J. H. MORGAN. *Corrosion Technology,* **3**, No. 6, 194-196 (1956) June.

The criterion of sufficient protection is that the potential of the cathodic structure shall be more negative than a certain critical value relative to the surrounding electrolyte. The operative factors are analyzed so that an economical design can be achieved.—BNF.   12528

5.2.1

Cathodic Protection Circuits. E. W. SCHWARZ AND R. M. WAINWRIGHT. Paper, AIEE Pacific Gen. Mtg., Butte, Montana, August 15-18, 1955. *Trans. Am. Inst. Elec. Engrs.,* Sec. 2. Applications and Industry, No. 21, 311-315 (1955).

Outlines corrosion problem along with advantages and disadvantages of present methods of attack. Purpose and implications of equivalent electric network and how it may be solved for corroding cell; use of present methods of circuit analysis to establish criterion for cathodic protection. Diagrams. 4 references.—BTR.
11527

5.2.1

Pitfalls to Avoid in the Design of a Cathodic Protection System. WAYNE A.

JOHNSON. *Pipe Line Ind.,* **4**, 24-26 (1956) March.

Consideration of these pitfalls will save money initially, cut operating expense, insure maximum efficiency. Graphs, diagrams.—MR.   11602

5.2.1, 1.7.3

Cathodic Protection Calls for Co-Existence. G. CORFIELD. *Gas,* **32**, No. 2, 65-66 (1956) February.

Organizations are being formed to prevent interference with and possible damage of adjacent underground structures of neighboring cathodic protection installations. Policy and procedure for such a cathodic protection committee are presented.—INCO.   1159.

5.2.1, 4.6.11

The Cathodic Protection of Metallic Structures in Marine Environments. W. A. BOWEN, JR. *Corrosion,* **12**, No. 7, 317t-330t (1956) July.

Theoretical and practical considerations involved in using cathodic protection in sea water are covered, including anode location, polarization, economics and other factors. Specific cases of cathodic protection application are mentioned, including drydocks and ships. Means of checking the effectiveness of cathodic protection are reviewed. The importance of supervision by competent personnel is mentioned, as is automatic control of potentials. Other topics discussed include use of compartmented cells, effect of cathodic protection current on marine growth and problems involved in making cathodic protection automatic.
11645

5.2.1

Cathodic Protection. W. GODFREY WAITE. *J. Junior Inst. Eng.,* **65**, No. 10, 293-305 (1955).

The theory of cathodic protection is outlined and its applications described.—MA.   11820

5.2.1, 5.4.5, 8.9.3

Pipelining Oil and Gas Products. Part III. Protecting Buried Lines with Drainage Bonds. O. C. MUDD. *Petroleo Interamericano,* **13**, No. 10, 74-76 (1955) Oct.

Use of electrical-current drainage bonds in the cathodic protection of pipelines, is discussed. The drainage bonds are primarily installed to establish equal protection between adjacent structures and to alleviate damage to nearby unprotected structures. The need for better coating is also discussed. Requirements of a good coating are 1) resistance to cold flow; 2) some resiliences; 3) low moisture transmission; 4) good bonding qualities; 5) immunity to fracture by temperature change or mechanical shock; and 6) reasonable cost and easy application.
11757

5.2.1, 8.4.3

Application of Cathodic Protection to 48 Well Casings and Associated Production Facilities at Waskom Field. G. L. DOREMUS, W. W. MACH AND J. J. LAWNICK. *Corrosion,* **12**, No. 8, 415t-421t (1956) Aug.

Casing failures caused by external corrosion attack led to an engineering study to obtain design data and costs for a multiple rectifier type cathodic protection system for 48 wells. This protective system was subsequently installed in an effort to prevent further costly casing repairs.

Difficulties encountered in obtaining the desired current drain of 1.5-2.0 am-

peres from each well and solutions to these problems are discussed. In final form the multiple rectifier installation provided all protective current for approximately 75 percent of the wells, while magnesium anodes were used exclusively or in supplement to rectifier drainage for the remainder.

All of the coated gas lines, an appreciable portion of the bare oil gathering lines and most of the production storage tank bottoms in the field were necessarily included in the cathodic protection system. In addition a separate rectifier-graphite anode system with new design features was installed for protection of an emulsion treater and brine handling equipment associated with a water-flood project in the field.   11891

5.2.1, 3.5.8
Effect of External Current and Cathode Polarization by Protectors on Increase of Fatigue Strength During Corrosion. (In Russian.) L. A. GLIKMAN AND L. A. SUPRUN. *Metallovedenie i Obrabotka Metallov*, No. 6, 10-15 (1956) Dec.

Fatigue curves for carbon-steel test specimens in air and salt solution with and without anodes of zinc-magnesium alloy. Effect of density of cathode current on corrosion-fatigue strength. Table, graphs, diagrams. Nine references. —MR.   12430

5.2.1, 8.4.3
Cathodic Protection Reaches up to Cover the Splash Zone. MAURICE A. RIORDAN. *World Oil*, **142**, 250 + 4 pages (1956) June.

A jacket made from molding paster, gypsum and fresh water creates an environment that will support proper current flow. Photographs, diagrams. One reference.—BTR.   12564

5.2.1, 8.9.5
Cathodic Protection and Shipping—Practical Considerations. A. W. HUBBARD. *Corrosion Prevention and Control*, **3**, 47-49 (1956) June.

Application to tanker cargo-ballast compartments and hull surfaces. Limitations of the galvanic system.—BTR.   12506

5.2.2
Zinc Anodes for Ships. H. S. PREISER. *Bureau of Ships J.*, **2**, 15-17 (1956) June.

Iron impurity was found to be the controlling factor in the ability of zincs to sustain continuous activity. Maximum iron that can be tolerated is 0.0014%. Diagrams, graph.—BTR.   12540

5.2.2
The Behavior of High-Grade Zinc as a Galvanic Anode. H. SHIGENO AND H. YOSHINO. *Corrosion Engineering*, **5**, No. 3, 33-37 (1956) June.

Long term fundamental tests were carried out concerning the anode behavior of various grades of zinc in synthetic seawater at room temperature. The results obtained were as follows: 1) Under an anodic current (1 mA/cm²), the anode potential of some grades of zinc became cathodic with the lapse of time. While, in the case of special high grade zinc (approx. 99.99% and 99.995% pure), the potential of —0.95~—1.0 V (referred to satd. calomel) was fully maintained. 2) Linear relations were clearly observed between the degree of increase of anode potential and the output current efficiency or rate of self-corrosion. 3) The effect of amalgamation which decreases the anodic polarization was confirmed

only in the case of high-grade zinc.—JSPS.   12593

5.2.2, 6.4.4
A Mechanism for the Anodic Dissolution of Magnesium. J. H. GREENBLATT. *J. Electrochem. Soc.*, **103**, 539-543 (1956) October.

Magnesium anodes were electrolyzed in 3% sodium chloride solution in a simple electrolysis cell. Magnesium in the anolyte, magnesium in the corrosion product, total hydrogen evolved and weight loss were determined. It was found that the quantities soluble magnesium, insoluble magnesium, magnesium calculated from the current passed were in approximate one-to-one relationship with each other and all of these quantities are roughly half of the total weight loss. Hydrogen evolved was always slightly less than the soluble and insoluble magnesium. These facts are explained and integrated into existing knowledge of the behavior of magnesium anodes by postulating that magnesium dissolves in the solution investigated mainly as a univalent ion followed by reaction of this univalent ion with water.   12463

5.2.2, 8.9.5
Corrosion Control in Tankers by Cathodic Protection. J. S. GERRARD. *Corrosion Prevention & Control*, **3**, No. 6, 37-38 (1956) June.

Reviews corrosion in tanker ballast compartments and mechanism of cathodic protection with emphasis on use of Mapel finned magnesium anode, which combines functions of main and booster anodes. Initial large surface area of anode results in creation of high current density forming initial calcareous deposit. After sacrifice of fin, current output of anode reduces, remains constant and maintains initial polarization and calcareous film.—INCO.   12437

5.2.4, 7.7, 4.5.2
Potential Criteria for the Cathodic Protection of Lead Cable Sheath, K. G. COMPTON. *Corrosion*, **12**, No. 11, 553t-560t (1956) November.

A report is made of the study of the static and dynamic potentials of lead cable sheath in 48 soils from various sections of the United States. Soils have been selected as representative of those actually in contact with cable sheaths. Anodic and cathodic polarization curves in representative soils, using a null bridge technique, are given to illustrate the potential changes accompanying corrosion and cathodic protection. Data indicate that significant corrosion may occur at potentials near the static potential of the lead sheath for that particular soil. To achieve cathodic protection it appears that the lead sheath should be polarized about 100 millivolts more negative than its static potential in the particular soil. In most soils this would require polarization to about 700 millivolts negative to the saturated copper-copper sulfate electrode.   12451

5.2.4
Major Factors in the Cathodic Protection of Steel in Sea Water. L. J. WALDRON, E. E. NELSON AND M. H. PETERSON. Naval Research Laboratory Rept. August, 1955, 21 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 111807).

Examination of data obtained by NRL and other laboratories shows that the best available criterion for the cathodic

protection of steel in sea water is polarization to —0.85 volt to a copper-copper sulfate electrode. There is evidence that this is inadequate in waters heavily polluted by organic wastes, in the presence of anaerobic bacteria and in the presence of certain types of fouling. Research indicates that the major forces influencing current distribution in cathodic protection are water resistivity and polarization. Relatively high water resistivity tends to give nonuniform distribution of current, while high polarization produces uniform distribution. Mathematical solutions have been derived for the simplest cases and aid in understanding the factors involved.   11855

5.3 Metallic Coatings

5.3.2
Protection Against Corrosion. Pt. II. The Ground Metal and Its Coating. Pt. III. The Use of Metallic Coatings. P. MORISSET. *Industrial Finishing*, **9**, Nos. 94, 95, 507-510, 569-574 (1956) April, May.

II. Shows that a metallic coating only has significance if its thickness is specified. Anodic and cathodic coatings, as well as the various factors promoting a good corrosion resistant coating are covered. Diagrams, graphs, 5 references.

III. Properties of electrodeposited coating metals and conditions under which they are likely to be used. Table, 4 references.—MR.   12516

5.3.2
Sprayed Aluminium Coatings. (In German.) H. REININGER. *Aluminium*, **32**, No. 8, 480-485 (1956) August.

The development of metal spraying techniques is traced and the practical experience collected in spraying steel with aluminum to provide protection from corrosion and scaling, as recorded in the international technical literature, is summarized. Data are presented concerning the thickness of the aluminum coating required in various corrosive media, such as industrial and marine atmospheres and also sea water. Some representative examples of practical applications of aluminum spraying are given. It is said that sprayed pure aluminum coatings also find application as protection for copper-containing aluminum and magnesium alloys. A further special type of metal spraying, called Alumetization, is discussed. This process embodies a subsequent treatment of the sprayed aluminum coating, viz. the application of a sodium silicate covering layer and heating between 950 and 1000 C. By diffusion of the aluminum coating into the ground metal an alloy-bond will result and upon solidification of the aluminum-iron solid solution an intermetallic compound Al_8Fe_2, will appear. Various techniques, using special steels and molybdenum alloys as ground metals and different aluminum alloys as coatings, are described. —ALL.   12579

5.3.2
Study of Corrosion and Wear Resistance of Calorized Steel. S. G. BOGDANOV. *Metallovedenie i Obrabotka Metallov*, No. 3, 25-31 (1955).

Corrosion resistance of steel specimens calorized at various temperatures and for various lengths of time, when exposed to 50% nitric acid, hydrochloric acid, sulfuric acid, picric acid, water vapor above 3% salt solution and, at high temperatures, to reducing and to

oxidizing atmospheres. Calorizing compound used. Results of frictional-wear test; testing procedure. Comparison with chromium-coated and with as-normalized uncalorized steels. Effect of quenching and tempering subsequent to calorizing upon resistance to wear and corrosion. Behavior of calorized steel after upsetting and continued heating for various times. Conclusions: Promise of calorizing for improved frictional wear resistance at high temperatures and for other applications. Best calorizing temperature and time. Translation available: Henry Brutcher, P. O. Box 157, Altadena, California.   11705

5.3.2

Proposed Substitutes for Nickel Plating. A. K. GRAHAM. *Plating*, **43**, No. 2, 218-220 (1956) Feb.; *Metal Finishing*, **54**, No. 2, 65-68 (1956) Feb.

Data on proposed substitutes for nickel plating were compiled from questionnaires sent to various companies and individuals. Substitute bright chromium coatings for nickel-chromium over ferrous basis metals include copper-nickel-chromium, copper-chromium, (copper + tin)-nickel-chromium, (copper + tin)-chromium, lead-antimony-chromium, white brass-chromium, chromium and copper-white brass-chromium. Proposed substitutes are more suitable in general for indoor service and except for heavy buffed copper-standard nickel-chromium combination are wholly inadequate as substitutes for nickel-chromium in severe outdoor service. Tables.—INCO.   11619

5.3.2

Hot-Dip Aluminized Steel—Its Preparation, Properties and Uses. M. L. HUGHES. Paper before Sheet & Strip Metal Users' Tech. Assoc., Conf. on "Modern Materials," London, October 10-11, 1955. *Sheet Metal Inds.*, **33**, No. 346, 87-97; disc., 97-98 (1956) February.

Reviews development of aluminizing: manufacture of hot-dip aluminized steel by calorizing, Armco aluminizing and Acco process for strip and wire, Mollerizing and Aldip processes; properties of aluminized steel including structure of coating, resistance to deformation, corrosion resistance (humidity, sulfur dioxide, flue gases) and resistance to heat. References are made to superior corrosion and oxidation resistance of aluminized stainless steels and to cases where hot-dip aluminized mild steels have replaced more expensive heat resisting steels (18 chromium-10 nickel steel in Diesel exhaust manifolds and stainless steel in military tank heat exchangers for 900 C service. Tables, graphs, photomicrographs.—INCO.   11637

5.3.2

Iron-Zinc Alloy Electroplating as a Protective and Decorative Finish for Steels. F. W. SALT. *Electroplating & Metal Finishing*, **9**, No. 1, 3-5 (1956) January.

Processes for electrodeposition of a wide range of iron-zinc alloy coatings on steel and properties of these alloys are described. Alloys with a low zinc content (6%) are hard, can be deposited bright and thus might be used as a base for other electro-finishes because of their smoothing action. Alloys with 35-65 zinc give good corrosion protection, are hard compared with zinc, seem suitable as a base for painting and give effective cathodic protection to the steel without being so liable to react with the paint as is pure zinc. 60% alloy can be deposited bright and might be suitable undercoat for chromium plating. Tests show that alloys of 35-65 zinc give corrosion protection equal to zinc. Alloys show good adhesion to the steel base and coated sheet or strip can be deformed without damage to the coating and the rates of electrodeposition are high. Photos, tables.—INCO.   11651

5.3.2

Electrodeposition of Titanium on Base Metals. M. E. SIBERT AND M. A. STEINBERG. *J. Electrochem. Soc.*, **102**, No. 11, 641-647 (1955) Nov.

Adherent coatings of titanium up to 0.005-inch thick could be electrodeposited on steel and other basis metals from fused sodium chloride/potassium fluotitanate mixtures. The coatings were bonded by an alloy intermediate layer and gave good corrosion protection.—BNF.   11510

5.3.3, 2.5, 1.6

Specification and Tests for Electrodeposited Metallic Coatings. Brochure, September, 1955, 96 pp. American Society for Testing Materials and American Electroplaters' Society. Available from ASTM, 1916 Race St., Philadelphia 3, Pa.

This issue collects 17 items (specifications, methods of testing and recommended practices), dating from 1949 to 1955. All 7 specifications have been revised in 1955; tentative method for acetic acid-salt-spray (fog) testing has been added since previous edition.—BNF.   11684

5.3.2

Precious Metal Plating: Uses Expand in Industry. P. J. SLOANE AND I. CROSS.

Harper-Leader, Inc. *Iron Age*, **176**, No. 20, 120-123 (1955) Nov. 17.

Precious metal plating, once considered too expensive for industrial use, is rapidly finding its way as a low-cost method of achieving optimum service ability. Electronic components serve as a major field for precious metal plating, with the more common metals in use being gold, silver, rhodium, platinum and palladium. The use of silver in electronics and as a non-galling anti-friction surface is widespread. Typical applications include silverplated fasteners for jet engines and thin coatings of silver on bearing surfaces. Precious metal plating also aids microwave transmission. Parts plated with rhodium are excellent for contact surfaces requiring a low stable resistance because they remain completely free of surface films. Almost complete chemical inertness of rhodium is an asset.—INCO.   11011

5.3.2, 3.5.8

The Effect of Different Chromium Deposits on the Fatigue Strength of Hardened Steel. J. E. Stareck, E. J. Seyb and A. C. Tulumello. Paper before Am. Electroplaters' Soc., 42nd Ann. Conv., Cleveland, 1955. *Plating*, **42**, No. 11, 1395-1402 (1955) Nov.

Fatigue properties of hardened SAE 4140 when plated with different types of chromium were investigated. Stress in the chromium deposit is the primary factor in determining the fatigue limit. The crack pattern is related to stress and thus indirectly to fatigue in unbaked deposits. Neither hydrogen embrittlement of base metal or harline cracks formed during electrodeposition, which might act as notches, can account for experimental results. Development of baths and plating conditions which give improved fatigue properties is discussed. For comparison with improved chromium deposits, deposits from dull, Watt's type nickel, bright nickel with an organic brightener, copper from pyrophosphate type bath and lead plate were tested at 0.001-inch thickness on SAE 4140. Watt's type nickel gave a fatigue limit of only 45,000 psi while bright nickel gave value of 85,000 psi., agreeing with findings with softer steel that compressively stressed bright nickel gives better fatigue properties than Watt's nickel with tensile stress. Tables, graphs. 16 references.—INCO.   11009

5.3.2, 3.5.8

Internal Stresses in Electrodeposits of Nickel. A. G. Samartsev and Yu. V. Lyzlov. *J. Phys. Chem., USSR* (Zhur. Fiz. Khim.), **29**, 374-379 (1955); *Chem. Absts.*, **49**, 10093 (1955) August 10.

When nickel was deposited on stainless-steel ribbon from bath of nickel sulfate, orthoboric acid and potassium chloride, "bending" of ribbon was proportional to amount deposited and almost independent of current density (5-25 ma./sq.cm.). Stresses in deposits were caused by volume changes in intercrystalline layers and by contraction of lattice, due to liberation of hydrogen.—INCO.   10978

5.3.2

Tin-Nickel Alloy Plated Coatings. R. T. Gore. *Materials & Methods*, **42**, No. 4, 102-105 (1955) October.

Properties of deposit and details of plating process for tin-nickel alloy coatings. Tin-nickel alloy is deposited as an intermetallic compound of 65 tin and 35 nickel. Plate thickness, throwing power, appearance, corrosion resistance, resistance to tarnishing, solderability, hardness and wear resistance, ductility, internal stress and temperature resistance are discussed. Ap-

plications include chemical processing equipment, food machinery castings, small parts (screws, nuts) and electronic parts. Plating process is outlined. Tables present data on resistance of tin-nickel to various corrosive chemicals in solution and in atmosphere.—INCO.   11480

5.3.2
Copper-Tin-Zinc Plating. J. B. Mohler. *Metal Finishing,* **53,** No. 10, 47-51 (1955) October.

A survey of a wide range of binary and ternary copper-tin-zinc alloys deposited from an alkaline cyanide bath: copper-tin-zinc (55/30/15), copper-tin (93/7, 80/20, 60/40 and 2/98), copper-zinc (92/8, 80/20, 75/25, and 25/75) and tin-zinc (80/20). Properties and application (e.g., bearing surfaces, undercoating and decorative applications) for each alloy are given. Control of alkaline cyanide bath for correct alloy deposition; metal ion content, free cyanide and free alkali, temperature, cathode efficiency, composition of the deposits, etc. 16 references.—BNF.   11419

5.3.2
Effect of Deposit Thickness on the Structure and Properties of Electrodeposited Metals. N. P. Fedot'ev, N. P. Gnusin and P. M. Vyacheslavov. *J. Applied Chem., USSR* (Zhur. Prikladnoi Khimii), **28,** No. 6, 634-637 (1955) June.

Above studied during deposition of copper, zinc and cadmium from acidic baths. 4 references, 5 figures.—ATS. Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.   11457

5.3.2
The Structure of Electrodeposited Alloys. Part IX. Silver-Thallium Alloys. (In German.) E. Raub and F. Sautter. *Metalloberflache,* Sec. B, **9,** No. 10, 145B-147B (1955) October.

Electrodeposition investigated from a silver-potassium cyanide bath with added thallous sulfate; cathode potential-current density, composition of deposit vs. current density, hardness of deposit vs. thallium content, alteration of lattice constants of electrodeposited 11.7 percent thallium alloy on annealing at 150C and of lattice constants and hardness of 9.3 percent thallium alloy on annealing at 200C. Structure discussed and compared with that of other silver-alloy deposits.—BNF.   11505

5.3.2
Influence of Hydrogen on the Mechanical Properties of Electrolytic Nickel. (In Russian.) A. L. Rotinyan and others. *Doklady Akad. Nauk SSSR,* **104,** No. 5, 753-755 (1955) October 11.

Effect of pH of a Watts-type bath on current efficiency, composition (carbon, oxygen and hydrogen content), internal stress, hardness, tensile strength, elongation, behavior in Erichsen test and density of the deposits. Also dependence of internal stress on the concentration of "organic" impurities (pinewood, canvas, filter cloth) in the electrolyte. Concludes that adsorbed hydroxides, basic salts or organic compounds containing hydrogen have an important influence on the properties of the deposits, but that there is no evidence for any action by "gaseous" hydrogen.—BNF.   11489

5.3.2, 1.6
Corrosion Protection with Aluminum Coatings. Part III. (In Dutch.) Brochure, February, 1956, 58 pp. E. M. J. Mulders, W. G. R. de Jager and J. W. Boon. Metaalinstituut TNO, Delft, Holland.

This is Part III of the institute's series of reports on the laboratory testing of aluminum and aluminum coated steel. Results of test series IV and V and of one of the sixth proof series are included. Data are given on physical changes and weight losses of materials submerged in water. Galvanic action between aluminum, steel, zinc-coated steel, are tabulated.   11376

5.3.2, 7.1
The Improvement of Bearings by Electrodeposition (of Lead, Lead-Indium, and Lead-Tin Coatings). W. Roggendorf. *Metalloberflache, A,* **9,** No. 5, 76-77 (1955).

Electrodeposited films of lead, or better still, lead-tin or lead-indium on the bearing surfaces of cast iron, bronze, lead-bronze, silver and silver alloy bearings considerably enhance their effectiveness. Data are given as to the compositions and operating conditions of the baths employed for producing such films. Lead is usually deposited from a fluoborate bath. However, as pure lead is rapidly attacked by the mineral and fatty acids contained in lubricants, a lead-indium alloy is more suitable; this is formed by overlaying the lead with a thin film of indium from a cyanide bath and then giving a diffusion heat-treatment at 150-175C, thereby producing a lead-indium alloy, the indium content of which is usually about 3% or, for special purposes, ~10%. Lead-tin alloys can be produced in a similar manner, using a stannate bath, or by alloy (90:10 lead-tin is common) deposition from a fluoborate bath. In the presence of mineral and fatty acids corrosion losses (for equal surface areas over equal periods of time) are in the ratio lead: lead $+ 4\%$ indium: lead $+ 10\%$ indium: lead $+ 10\%$ tin = 70:2:0.7-1.4:0.2-0.3. —MA.   11501

5.3.2, 8.8.5
Improvement of Wear Resistance of Cold-Header Dies by Gas Chromizing. G. N. Dubinin and B. V. Gal'chenko. *Stanki i Instrument,* **26,** No. 8, 17 (1955).

Study of advantages of gas chromizing of hammers and dies for the cold-heading of bolts, screws and rivets. Performance of dies (1 carbon, 0.20 manganese, 0.30 silicon, max.) heat treated after chromizing, compared with as-chromized dies. Service life of unchromized dies as against chromized plus heat treated ones. Processes occurring in die interior during service. Translation available: Henry Brutcher, P. O. Box 157, Altadena, California.   11475

5.3.2
The Heat Resistance and Applications of Hot Dip Aluminized Steel. M. L. Hughes and D. F. G. Thomas. *Metallurgia,* **52,** No. 313, 241-245 (1955) Nov.

Results of scaling tests (620-800 C in air and air containing some sulfur dioxide) on hot-dipped aluminized steel panels BISRA fluxless process) are satisfactory and compare favorably with aluminium-silicon coatings: some results of tests on sprayed coating, on aluminized Armco iron sheet and steel hot-dipped by the Aldip process are given for comparison. This paper is based on British Iron Steel Res. Assoc. Report RRE 527 made available to Brit. Non-Ferrous Metals Res. Assoc. members in October, 1955.—BNF.   11752

5.3.2
Hot-Dip Aluminum Coating for Cast Iron. Shigetomo Ueda. *Foundry Trade J.,* **99,** No. 2039, 359-361 (1955).

The effect of hot-dip aluminum coat-

ing on the resistance of steels and cast iron to attack by sulfur-bearing gases was studied. Variables chosen for investigation were dipping time (1-60 min.), temperature (700-900 C), and specimen size. Cast iron is more difficult to coat than steel, but coatings 0.35-0.4 mm in thickness are obtained by immersion in molten aluminum for 5-15 min. at 800-900 C. Laboratory tests showed that the coated iron had an excellent resistance to attack by hydrogen sulfide at 550 and 900 C and these results were confirmed by semi-industrial trials.—MA.   11811

5.3.2
Protection Against Corrosion by Hot Dip Galvanizing. (In French.) P. Morisset. *Corrosion et Anti-Corrosion,* **3,** No. 5, 238-252 (1955) Sept./Oct.

Protective value of coatings and electrochemical mechanism of corrosion are discussed in general, with zinc on iron as example; influence of basis metal structure and composition of coating, shape of part, etc., on corrosion protection; behavior of galvanized coatings in dry and damp air; effect of tropical climates, contact with various waters, air plus sulfur dioxide, foodstuffs, chemicals, etc. Application of galvanized products; also table of some ASTM specifications for galvanized parts.—BNF.   11835

5.3.2
Cementation of Copper with Beryllium. (In Italian.) G. Venturello and V. Coen. *Metallurgia Italiana,* **47,** No. 10, 453-460 (1955) October.

Production of copper-beryllium coatings on copper specimens (to increase hardness, wear resistance and corrosion resistance without affecting electrical and thermal conductivity) by cementation in contact with copper-26.4% beryllium powder. The surface layer can be heat treated and hardnesses of over 400 Brinell have been obtained. X-ray studies have been made to determine the nature of the phases present.—BNF.   11853

5.3.4
Electrodeposits of Metals of the Platinum Group. (In French.) E. H. Laister. *Rev. Met.,* **52,** No. 9, 698-706 (1955) Sept.

Practical details of deposition of platinum, palladium and rhodium, with properties and applications of the deposits; also report of discussion.—BNF.   11840

5.3.4
Black Stains in Dry Galvanizing. (In German.) H. Bablik, F. Götzl and E. Nell. *Metalloberflache,* **10,** No. 2, 34-35 (1956) Feb.

Black stains in dry galvanizing are ungalvanized areas arising from failure of the aqueous flux owing to too high an aluminum content in the flux and particularly so if there is a high aluminum content in the zinc bath itself.—BNF.   11902

5.3.4
Bright Nickel Plating Solutions—Their Choice, Control and Operation. T. E. Such. *Electroplating & Metal Finishing,* **8,** Nos. 9, 10, 308-315 347-350 (1955) Sept., Oct.

Describes the different types of fully and semi-bright plating solutions in use and discusses their relatively advantages and disadvantages, particularly in relation to brightness, levelling, ductility and residual stress. Control and purification schemes are dealt with. Once the necessary experience has been ob-

tained, the Hull cell gives a satisfactory means of controlling addition agent concentration as well as revealing the presence of metallic or organic impurities. As commonly employed, the bending test for ductility is not sufficiently sensitive nor does it give quantitative results. Records of variations in stress and ductility occurring from day to day are essential for satisfactory control. Schemes are given and lay-out of plant suggested for carbon purification and for combined carbon and high pH purification of bright nickel plating solutions. Use of anti-stress agents is discussed. Special features of the plant required for bright nickel, characteristics of bright nickel plating such as sensitivity to cleanness of the basis metal, throwing power of the solution, use of wetting agents, treatment of passive deposits before chromium plating and production control tests of bright nickel deposits are included.—INCO.   10997

5.3.4
Present Position of Electrodeposited Tin-Nickel Alloy Coatings in France. (In French.) G. STEMPFEL. *Metaux, Corrosion-Industries*, **30**, No. 356, 173-176 (1955) April.

A brief survey of the application of tin-nickel coatings. Slightly modified bath composition (recommended by the Centre d'Information de l'Etain) is given and also some recommendations for industrial application and control.—BNF.   11002

5.3.4
Peculiarities of the Cathodic Process in Copper Pyrophosphate Baths. (In Russian.) E. A. UKSHE AND A. I. LEVIN. *J. Applied Chem.*, USSR (Zhurnal Prikladnoi Khimii), **28**, No. 4, 388-393 (1955) April.

Baths contained cupric sulfate and sodius pyrophosphate. Dependence of deposit quality on bath composition and current density has been determined. Also reasons for formation of surface film on deposits and for high overvoltage.—BNF.   11022

5.3.4, 5.4.2
Electrophoretic Deposition of Metallic and Composite Coatings. J. J. SHYNE, H. N. BARR, W. D. FLETCHER AND H. C. SCHEIBLE. Paper before Am. Electroplaters' Soc., 42nd Ann. Conv., Cleveland, 1955. *Proc. Am. Electroplaters' Soc.*, **1955**, 115-118; *Plating*, **42**, No. 10, 1255-1258 (1955) October.

Theory of electrophoretic deposition is reviewed. Electrophoretic deposition of nickel, nickel-chromium and nickel-chromium-iron castings to base metals has been developed. Composite coatings of metals and nonmetals, such as molybdenum-disulfide and nickel-silicon carbide composites have also been deposited. Techniques for bonding were developed, either by deposition of a hydrogen-reducible oxide or by electrolytic deposition of a metal through pores in coating. Time vs. current and thickness vs. time curves are given. Photomicrographs.—INCO.   11067

5.3.4, 5.9.4
The Temperatures Attained at the Surfaces of Growing Deposits and the Origin of Stress in Deposits. H. WILMAN. *Proc. Phys. Soc.* (London), Sec. B, **68**, No. 7, 474-476 (1955) July 1.

Evidence presented to prove the very high temperatures reached on the immediate surface region of deposits; condensation from the vapor in a vacuum, electrodeposition and adonic oxidation are discussed for copper, silver, gold, nickel, iron and palladium; temperatures of 200-230C for copper, 200C for silver and gold, 530-600C for nickel and 350-450C for iron in condensed deposits; 300C for anodized beryllium, 650C for anodized aluminum are claimed. These conclusions are supported by the author's explanation of his observations on the stress developed in these deposits.—BNF.   11047

5.3.4, 6.3.19
Production of High-Grade Electroplated Coatings on Zinc Alloy Parts. (In Russian.) G. S. VOZDVIZHENSKII AND OTHERS. *J. Applied Chem.*, USSR (Zhurnal Prikladnoi Khimii), **28**, No. 5, 484-489 (1955) May; Summary translation: *Ind. Finishing*, **9**, No. 86, 36 (1955) August.

Effect of impurities and inclusions in zinc alloy castings on the blistering of electrodeposits; optimum bath composition for copper plating (cyanide bath).—BNF.   11034

5.3.2, 5.3.3
Electroplated Coatings. J. B. MOHLER. Kaiser Aluminum & Chem. Corp. *Materials & Methods*, **44**, No. 1, 117-132 (1956) July.

Factors in selecting electroplated coatings are discussed as to plate properties, design of part, base metal and specifications. Tables of specifications on thickness of electrodeposited coatings are given. Discussion of characteristics of common electroplates includes nickel, chromium and copper. Applications of

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electroplates as to appearance, corrosion protection, low cost, wear resistance and salvage are given. Tables give principal applications for common electroplates. Photos.—INCO.   12521

5.3.4

Basis Metals and Electrodeposited Coating. (In German.) J. FISCHER. *Metall*, 10, No. 11/12, 499-504 (1956) June.

A survey, based on a long bibliography, on the importance of the nature and surface condition of the basis metal, and of pre-treatments (cleaning, degreasing, etc.) prior to application of electrodeposited coatings; concluding with notes on suitable pretreatments for powder metal products, aluminum and alloys, magnesium and alloys, stainless

steel, molybdenum, zirconium and titanium.—BNF.   12450

5.3.4

Modern Electroplating Processes. (In German.) E. ROTH. *Metall*, 10, No. 11/12, 505-513 (1956) June.

Notes on plating of nickel, copper, chromium, zinc and cadmium, tin and lead, noble metals, alloys; plating on zinc-base die castings and aluminum; automatic plating; small parts. Includes tables showing respectively resistance to 20% salt spray of various thicknesses of electrodeposits and hardness of electrodeposits.—BNF.   12580

5.3.4, 1.4, 2.3.7

Metallizing Bibliography. AWS Pub. No. C2, 5, 1956, 35 pp. Available from:

American Welding Society, 33 W. 39 St., New York 18, New York.

Annotated abstracts of 181 articles on metallizing which have been published since 1913. Items are grouped together under headings: Equipment, processes, applications, testing, theory, costs and miscellaneous. List of periodicals with addresses is included.   12416

5.3.4, 5.9.2

Elementary Topics for Research in Metal Finishing. I. Electroplating Pretreatments. II. The Electroplating Process. III. Electrodeposited Coatings. C. JAMES. *Product Finishing*, 9, Nos. 4, 5, 6, 54-62, 76-89, 65-72 (1956) April, May, June. (In Progress.)

I. A practical discussion of solvent, aqueous alkali and emulsion cleaning; acid dips and pickles; transfer from cleaning, including alkali and acidic dips. Author discusses good and bad practice, pointing out details where further investigation is required, though he agrees that in some instances all that may be necessary is a search of published information.

II. Comments on purity of chemicals, with tables of analysis for cadmium oxide and $Zn(Cd)_2$; anode problems (including analytical values for cadmium, nickel and tin anodes); work suspension; wash waters (data on mains water from different sources).

III. Deposit distribution, with various examples; alloy plating; measurement of deposit thickness (no reference to new BNF thermoelectric thickness gauge); treatments after plating (with a table showing effects of after-treatments on corrosion resistance of zinc-plated steel screws).—BNF.   12481

5.3.4, 7.2

Aluminizing Curbs High-Temperature Erosion. W. G. PATTON. *Iron Age*, 177, No. 2, 74-77 (1956).

Automobile engine valves are aluminized to improve corrosion-resistance. Inlet and exhaust valves in the finished state are treated separately. They are induction-heated to 450 F (230 C), rotated at 500 rpm and sprayed with aluminum from a modified oxyacetylene torch. The valves are reheated to 1450 F (790 C) to complete the formation of the iron-aluminum alloy layer which is < 0.001 in. thick.—MA.   12534

5.4 Non-Metallic Coatings and Paints

5.4.2, 7.2, 5.4.3

Design of Steel Pipe With Cement Coating and Lining. E. SHAW COLE. *J. Am. Water Works Assoc.*, 48, 131-138 (1956) Feb.

The pipe discussed in this paper is steel pipe with diameters of 30 inches or larger, which is protected by a cement coating and cement lining. Tables, photographs, graph. 8 references.—BTR.   11578

5.4.2

Plating with Carbide. R. H. ESHELMAN. *Tool Engr.*, 36, No. 1, 117-122 (1956) January.

Describes the flame-plating process, developed by Linde Air Products Co., which deposits a coating by blasting tungsten carbide particles through a gun, using explosive gases as a carrier. Coatings consist essentially of complex series of phases, derived from tungsten-carbon-cobalt system. Density is identical to that of solid cast material, poros-

ity is less than 1%, and adherence is excellent. Plating can be applied to steels, cast iron, copper, brass, bronze, molybdenum, titanium, nickel and magnesium. Chromium plate cannot be coated. Equipment limitations, physical and mechanical properties and applications are discussed. Coating is suitable for high temperature fretting corrosion resistance. Diagrams, photomicrographs. —INCO.   11579

5.4.5

Calcium Plumbate. A Post-War Development in Anti-Corrosive Paint Pigments. N. J. READ. *Corrosion Technology,* **3,** 119-123 (1956) April.

Like red lead it provides protection by a combination of basic and oxidizing characteristics, as well as film-forming properties by interaction with linseed oil.

Photographs, tables, 2 references.—BTR.
                 12542

5.4.5

Industrial Applications for Vinyl Resin Finishes. FRANK A. RIDEOUT. *Org. Finishing,* **17,** 15-20 (1956) May.

Vinyl copolymer properties; solvents for vinyl coatings; hot spray application of vinyl maintenance paint; plasticizers, pigmentation and primers; dispersion coatings. Table, photographs.—MR.
                 12566

5.4.5

Guarantees of Durability and Efficiency of Protection of Multicoat Anti-Corrosive Coatings of Paints. H. RABATE. *Peintures, Pigments, Vernis,* **32,** No. 1, 25-29 (1956).

Factors involved in such guarantees are discussed.—RPI.   12558

5.4.5

Red Lead in the Protection of Iron and Steel. Pt. I. H. MASSEILLE. *Corrosion Prevention and Control,* **3,** 35-37 (1956) June.

Causes of metal oxidation; protection of metal surfaces; characteristics and properties of paints. (To be continued.) —BTR.   12550

5.4.5

Plastic Coating of Metals. (In German.) G. SHULTZ. *Schweiz. Archiv Angew. Wiss. Tech.,* **22,** No. 6, 178-182 (1956) June.

Application of plastics as powder, paste, foil or plate.—MR.   12586

5.4.5

Thin Films of Polytetrafluoroethylene Resin (Teflon) as Lubricants and Preservative Coatings for Metals. V. C. FRITZ-SIMMONS AND W. A. ZISMAN. Naval Research Lab., June, 1956, 32 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 121161).

The report summarizes experimental work and field tests on a number of applications of Teflon to guns and ammunition, submarines, aircraft and other equipment. An appendix contains a number of essential techniques developed by NRL which insure minimum friction, maximum durability, good adhesion and good corrosion-prevention properties.

Teflon is not a panacea for solving all lubricating problems without the use of oils and greases, the report points out. However, when properly used the coating is ideal in numerous applications of value to both the military and industry.
                 12431

5.4.5

Use of Baked Coatings in the Oil, Chemical and Processing Industries. G. J. DUESTERBERG. *Corrosion,* **12,** No. 11, 576t-578t (1956) November.

Baked coatings have three primary uses in the oil, chemical and processing industries: 1) To combat corrosion 2) To protect finished products from iron contamination 3) To eliminate growth of solids such as synthetic polymers, scale, salt and paraffin. Case histories are given to show how baked coatings have been used in industry to accomplish these tasks.

5.4.5, 2.3.7

Properties, Specifications, Tests and Recommendations for Coal Tar Coatings Part I. Hot Applied Coatings. W. F. FAIR, JR. *Corrosion,* **12,** No. 11, 579t-587t (1956) Nov.

Fundamental properties, long-term service characteristics and specification writing and testing for various kinds of hot applied coal tar enamels are described. Emphasis is directed to the importance of long-term testing of coating types previously found to perform satisfactorily in service in various environments over long periods of time. A brief history of the use of hot applied coal tar coatings also is given.

Technique of application and a list of commonly used types of pipe coating are given. Data are tabulated for eight plasticized and seven unplasticized enamels with respect to softening point, penetration, percent ash, specific gravity, high temperature sag and low temperature crack. Water absorption rates are plotted for several pipe line enamels. On other graphs the relationship between rate of shear and shearing stress is shown for a number of roofing pitches. Elec-

trical resistivity, soil stress resistance, and oil spillage resistivity are discussed in connection with coal tar enamels.
12447

5.5 Oil and Grease Coatings

5.5.1

Lanolin—As a Temporary Protective. H. SILMAN. *Corrosion Technology,* 3, 138-140, 153 (1956) May.

Lanolin is compared with various oils and greases as a rust preventive coating. Photographs, table, 4 references.—MR.
12592

5.8 Inhibitors and Passivators

5.8.2, 8.4.3

Use of Internal Corrosion Inhibitors in the Paris-Le Havre Pipeline. J. VINCENT-GENOD. Paper, Assoc. Francaise Tech. Petr. Meet. May 5, 1955. *Bull. Assoc. Francaise Techniciens Petrole,* No. 112, 405-418 (1955) July 31.

Injection of 0.25-1.3 ppm sodium nitrite in aqueous alkali at several points along the Paris-Le Havre pipeline, begun in August, 1953, almost eliminated sediment formation and improved the roughness factor of the internal pipe surface by the end of 1954. The inhibitor solution is removed by "hay tank" filters in the line and thus must be reinjected at each relay station. Injection of an alcoholic solution of an aliphatic amine acetate in addition to the sodium nitrite resulted in a slightly better smoothness of the pipe.
11809

5.8.1, 4.3.2

Inhibition of the Corrosion of Iron by

Acids by Insoluble Organic Inhibitors. (In French.) R. JENNY. *Corrosion et Anti-Corrosion,* 3, Nos. 5, 6, 189-209, 253-274 (1955) Sept./Oct., Nov./Dec.; *ibid.,* 4, No. 1, 4-21 (1956) Jan.

Study of insoluble organic inhibitors (various phenyl and alkyl mercaptans, aromatic aldehydes and furaldehyde were tested); effect of structure of inhibitor on degree and mechanism of inhibition; factors which prevent inhibitors from acting as such; detailed discussion on mechanism of inhibition. 78 references. —BNF.
11746

5.8.2

Inhibitors of Corrosion. (In German.) H. FISHER. *Z. Metallkunde,* 46, No. 5, 350-357 (1955) May.

A survey based on 27 references. Definition of inhibition; types of inhibition and inhibitors; mechanism; and degree of protection. Graphs, tables, diagrams, 21 references.—BNF.
11766

5.8.2, 4.6.1

Progress in Chemical Water Treatment for Increased Protection Against Corrosion. (In German.) L. W. HAASE. *Werkstoffe u. Korrosion,* 6, No. 3, 130-132 (1955) March.

Progress in inhibitors. Effects of small amounts of phosphate, silicate and fluoride additives considered.
11802

5.8.3, 5.5.3

Investigation of Action Mechanism of the Anticorrosion Admixtures to Oils by the Radioactive Indicator Method. (In Russian.) YU. S. ZASLAVSKII, S. E. KLEIN AND R. N. SHNEEROVA. *J. Phys. Chem., USSR* (Zhur. Fiz. Khim.), 29, 1815-1821 (1955) October.

Radiosulfur (S^{35}) and radiophosphorus (P^{32}) were used in anticorrosive admixtures to the mineral oil. The results of the study proved that a protective film forms over a metal with the help of the sulfur or phosphorus as the basic components of the admixture. The formation of the protective film in relation to time, temperature of oil, concentration of the admixture and the metal surfaces was established. Also, the complicated process of film formation, adsorption and chemical interaction is given. It was suggested that adsorption processes take place at lower temperatures. While chemical interactions prevail at high temperatures during which the sulfur penetrates the metal and the transfer of the metal into the oil occurs as a result of this chemical interaction.—NSA.
11883

5.9 Surface Treatment

5.9.2

On the Descaling and Chemical Polishing with Hydrogen Peroxide Solution. Part II. K. KAWAMURA. *Sumitomo Metals,* 7, No. 4, 18-31 (1955) Oct.

Study was made to clarify the mutual relation between the density and descaling or chemical polishing by changing the proportion of hydrogen peroxide, acid and water in every possible way of mixing against each kind of metal, making diagrams to find the proper ratio for a solution. Metals included Type 301, Timken 16-25-6, N-155, Nimonic 80A, 19-9 DL, S-816 and 18-8. The relation between the variety in the density of solution and the time necessary for its treatment, between density and the dissolving quantity of a metal and between the processing time for treatment and

variety in the dissolving quantity of a metal were studied.—INCO.
11755

5.9.2

Degreasing Systems and Their Choice. Part I. D. J. FISHLOCK. *Product Finishing,* 8, No. 8, 48-56 (1955) Aug.

The first of these two articles deals with solvent, vapor, ultrasonic and emulsion degreasing. Tables indicate which methods are suitable for particular metals and alloys (including zinc die castings) and which are best to remove certain dirts. Equipment for carrying out the various processes is illustrated.—ZDA.
11736

5.9.2

Metal Cleaning Studies Using Radioactive Tagged Soils. J. W. HENSLEY AND R. D. RING. *Plating,* 42, No. 9, 1137-1143 (1955) Sept.

Data presented on effects of cleaning time, concentration and current direction, surfactant, current density and initial stearic acid soil level. Procedures used in tests and comparison of tagged soils given.—BL.
11838

5.9.2

Pickling Processes Reviewed. Pt. V. Treating Copper and Its Alloys. Pt. VI. Pickling Zinc, Cadmium, Magnesium and Aluminium. D. J. FISHLOCK. *Product Finishing,* 9, Nos. 3, 4, 70-78; 63-70, 112 (1956) March, April.

Part V deals with various pickling baths for copper and alloys; bright dipping baths; chemical polishing; spotting out in nitric acid; pickling copper-beryllium and aluminum bronze; etching for plating.

Part VI. For zinc (slightly for cadmium) and magnesium a variety of pickling treatments and pre-treatments are given for improving finish and corrosion-resistance. For aluminum, reference is also made to electropolishing (Brytal and Alzak) and chemical polishing.—BNF.
12435

5.9.2, 3.2.2, 5.8.2

The Effect of Pickling Additions on Hydrogen Embrittlement. (In German.) A. AND R. KELLER. *Draht,* 7, No. 2, 35-38 (1956) Feb.

A detailed discussion of the causes and the factors affecting acid brittleness occupies the first half of the paper. The second half deals with a practical investigation of the effects of 18 different types of inhibitor. Tables show the results obtained with wire samples in 7.5% and 15% sulfuric acid solutions and it is concluded that it is possible to prevent embrittlement to a very large extent by the selection of suitable inhibitors, even though the material may be susceptible to this kind of attack.—ZDA.
12483

6. MATERIALS OF CONSTRUCTION

6.1 General

6.1, 3.5.9

Today's Trends in Engineering Materials, *Machine Design,* 28, No. 11, 85-129 (1956) May 31.

Papers include: Light Alloys, P. D. Frost (p. 86-89); Electrical Insulation Materials, L. Greer (90-94); Materials for High Temperatures, C. L. Clark (p. 95-98); High-Strength Adhesives for Metal Bonding, R. F. Blomquist (p. 99-103); Corrosion-Resistant Structural

Materials, H. T. Francis (p. 104-107); Sleeve Bearing Materials, J. B. Mohler (p. 108-110); Metals for Low Temperatures, A. L. Tarr (p. 111-116); Packing and Gasket Materials, R. H. Koch (p. 117-120); Spring Alloys, M. G. Fangemann (p. 121-125); Materials for Wear Resistance, V. Pulsifer (p. 126-129).—INCO.   12531

6.2 Ferrous Metals and Alloys

6.2.1

Stainless Steels Including Other Ferrous Alloys. W. A. LUCE, Duriron Co., Inc. *Ind. & Eng. Chem.*, **47**, No. 9, Pt. 2, 2023-2035 (1955) September.

General review of recent literature covering corrosion, mechanical properties and structure, high temperature properties, welding and fabrication as well as general information on stainless steels and ferrous alloys. Mention is made of high-silicon irons, iron-nickel alloys and manganese steel. 198 references.—INCO.   10851

6.2.2

Notch Ductility of Malleable Irons. G. A. SANDOZ, N. C. HOWELLS, H. F. BISHOP AND W. S. PELLINI. Naval Research Laboratory, May, 1956, 22 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 121033).

Drop-weight tests on malleable irons were conducted to establish nil ductility transition (NDT), or the temperature at which there is a complete loss of ductility in the presence of a sharp, crack-like notch. The notch was developed by use of a brittle weld, or crack-starter, ordinarily used for hard surfacing. Explosion tests of plates with crack-starter welds also were conducted to establish the relative resistance to starting and propagation of brittle fractures at temperatures above the NDT temperature. Charpy V curves were established for various irons and related to behavior of irons in both tests.   12563

6.2.2

The Corrosion of Cast Iron. R. I. HIGGINS. *J. Research and Development*, Brit. Cast Iron Res. Assoc., **6**, No. 4, 165-177 (1956) Feb.

Factual discussion of the behavior and suitability of different types of cast iron in various conditions and media of corrosion. Types considered are unalloyed cast iron, low alloy cast irons (3-5 nickel, 0.5-1.0 copper, up to 1 chromium or up to 0.5 molybdenum), and high alloy cast irons such as Ni-Resist and Nicrosilal, high silicon cast iron and high chromium cast iron. Data are given on influence of type of metal (chemical composition and microstructure) and of environment of mineral and organic acids and alkalies. Corrosive action of various salt solutions, natural and industrial waters, atmosphere and soil are considered. Graphs show corrosion rate of cast irons in sulfuric acid, hydrochloric acid and sodium hydroxide.—INCO.   12441

6.2.2, 3.7.2, 3.8.2

Fundamental Studies on Corrosion of Alloys. Rept. V. Corrosion Rate of α-Solid Solution in Iron-Silicon System. N. OHTANI. *J. Japan Inst. Metals*, **20**, No. 1, 46-48 (1956) Jan.

Using the normal electrode potentials, calculated thermodynamically from the activity of each component in molten state within the range of α-solid solution of iron-silicon alloys and the heat of activation in hydrogen electrode reaction, obtained from the absorption amount of hydrogen, the author discusses the fact that the variation of the corrosion rate of the alloys with silicon content was fairly consistent with experimental results.—JSPS.   12523

6.2.3, 6.2.4

Steels and Their Treatment for Engineering. J. G. RITCHIE. Paper before Mech. Engrs.' Assoc. (Australia), Victoria Div., September 15, 1955. *Australasian Engr.*, **1956**, 57-62, 72a, 72c, April 7.

Object of paper is to explain development of various engineering steel types, to describe functions of alloying elements, main types of heat treatment applied, metallurgical test techniques and aspects of failures and to remark on steel specifications for small engineering shop. Steels discussed include plain carbon, mild, medium carbon, machinery, tool and nickel case hardening steels. Hardening, tempering, normalizing and annealing are briefly reviewed and steps in case hardening process (carburizing, core refining, hardening and tempering) are considered in greater detail. Some remarks are made on weldability, fracture and fatigue failure. Tables, graphs, photomicrographs.—INCO.   12575

6.2.4

Effects of a Number of Heat Treating and Testing Variables on the Notch Strength of 4340 Steel. G. SACHS, V. WEISS AND E. P. KLIER. Paper before ASTM, 59th Ann. Mtg., Atlantic City, June 17-22, 1956. Am. Soc. Testing Materials Preprint, No. 71, 1956, 11 pp.

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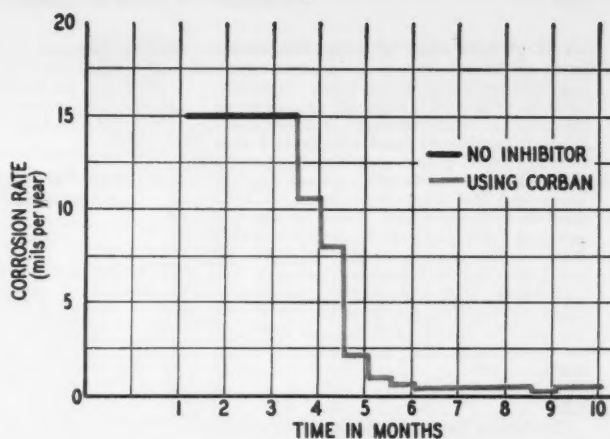
1 STANDARD TEST uses metal strips inserted in wellhead or tubing. Surface penetration or weight loss indicates degree of corrosion.
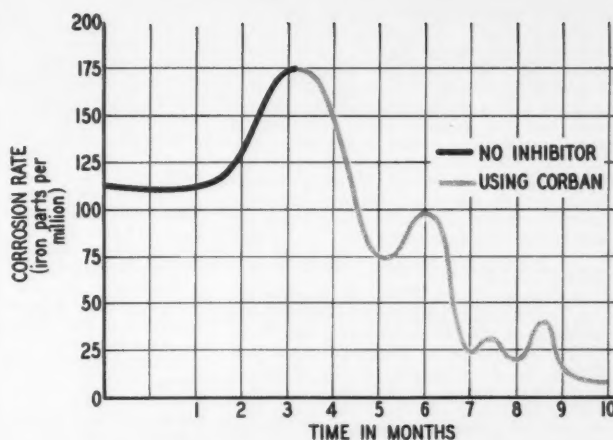
2 FLUID ANALYSIS is quick test of corrosion in gas condensate wells. Chart shows parts per million of dissolved iron in water sample.

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levels of 4340 steel to stress concentrations of different magnitude and at testing temperatures from room temperature to —320 F; range of existence of the 500 F embrittlement under static loading conditions; and effects of 2-step treatments promoting lower bainite structures on notch-strength characteristics and 500 F embrittlement of 4340 steel were determined. Tests on sharply notched bars disclose tendency of 4340 steel to be highly notch sensitive on static loading, if tempered between 500 and 700 F. 2-step quenching procedure leads to high strength steel conditions superior to those obtained on ordinary oil quenching and tempering. Tables, graphs.—INCO.   12583

6.2.4

Oxidation Resistant Silicon Aluminum Steels. E. A. Brandes. Special Report No. 2, August, 1956, 40 pp. Fulmer Research Institute, Ltd., Stoke Poges, Bucks, England.

Tests on steels containing up to 4% of silicon and up to 3% aluminum have shown that steels containing 2-3% silicon with 0.5 to 1% aluminum are comparable in resistance to oxidation at temperatures up to 900 C with 18% chromium, 8% nickel austenitic steel. The results of mechanical tests show that such steels have adequate ductility at room temperature to permit many metal-forming operations and that the ductility is not reduced by oxidation at temperatures up to 900 C. Carbon and manganese in quantities normally encountered in mild steel are without significant effect on the resistance to oxidation and the addition of manganese is recommended in order to minimize the adverse effect of segregated sulphur on the oxidation behavior. Scaling resistance in flue gas and steam is superior to mild steel and is further improved by aluminum coatings. (auth)   12377

6.2.4, 3.7.3, 1.6

A Survey of the Effect of Austenitizing Temperature and Rate of Continuous Cooling on the Structure and 700 F to 1200 F Properties of Three Low-Alloyed Steels. K. P. MacKay, A. P. Coldren, A. I. Rush and J. W. Freeman. University of Michigan. U. S. Wright Air Development Center, January, 1956, 78 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 121149).

The three steels studied were nickel-chromium-molybdenum (SAE 4340), 1.25 chromium-molybdenum-vanadium ("17-22-A"S), and 3 chromium-molybdenum-tungsten-vanadium (H-40). Martensite, martensitic-bainitic, bainitic and bainitic-ferritic structures were produced by oil quenching 1-inch rounds and air cooling 1-inch and simulated 3 and 6-inch rounds.

Results indicated that the fully bainitic structures which were predominantly in the upper bainite had maximum strength over the range of testing temperatures. In general, such structures were found in the larger, normalized sections and with higher austenitizing temperature. Since low values of ductility resulted from the higher temperature treatments, however, the best combinations of strength and ductility were obtained when the largest sections were normalized from the lower austenitizing temperatures (1750 degrees for SAE 4340 and "17-22-A"S, and 1950 degrees for H-40).

Regarding the effect of varying the

cooling rates of normalized bars, it was found that increases in strength occurred for all three steels as the effective bar diameter was increased from 1 inch to 6 inches.   12471

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.2, 3.8.2

Dissolution of Cadmium in Chromic Solutions. Cecil V. King and Edward Hillner. *J. Electrochem. Soc.,* 103, No. 5, 261-265 (1956) May.

Dissolution rate of cadmium was determined in dilute chromic chloride solutions containing hydrochloric acid up to 4M as functions of concentration, stirring speed and temperature. The potential of the metal in these solutions is essentially that of the cadmium-cadmium ion couple, and there is little if any anodic polarization. Graphs, tables. 15 references.—MR.   12511

6.3.4, 3.2.2, 3.7.2

Sulfur Embrittlement of Cobalt. D. L. Martin. Gen. Elec. Co. *J. Metals* (Trans. AIME), 8, No. 5, 578-579 (1956) May.

Describes eutectic embrittlement by sulfur of cobalt. Series of cobalt-sulfur alloys was prepared and studied to establish effect of sulfur on the hot-working characteristics of cobalt. Alloys were evaluated for hot brittleness by heating to 1000 C in a hydrogen furnace and swaging in air. Examination of microstructure revealed cobalt sulfide eutectic at grain boundaries. Upper sulfur embrittlement limit is 0.015%. Damaging effect of sulfur on ductility of cobalt is plotted. Photomicrographs, 13 references.—INCO.   12515

6.3.4, 3.5.9, 3.2.3

High Temperature Scaling of Cobalt-Chromium Alloys. C. A. Phalnikar, E. B. Evans and W. M. Baldwin, Jr. *J. Electrochem. Soc.,* 103, No. 8, 429-438 (1956) August.

Scaling rates and scale compositions of cobalt-chromium alloys were determined in the temperature range 900-1200 C. At any given temperature the scaling rate increased with low chromium additions, then dropped precipitously with further additions reaching a minimum at about 25% chromium. Thereafter the scaling rate again increased approaching the scaling rate of chromium as the upper limit. Above a critical concentration of about 25% chromium, the scale consisted exclusively of chromic oxide. Below this critical concentration, complex scales consisting of the oxides of both cobalt and chromium were formed. The best scaling resistance was associated with a scale consisting predominantly of chromic oxide, not spinel. Schematic isothermal sections of the deduced cobalt-chromium-oxygen phase diagram were applied as an aid in interpreting the scaling behavior.   12551

6.3.6, 3.5.8

Micro-Structure of a Brittle Beta-Brass with 3.99% of Aluminum. (In French.) A. R. Bailey and C. Robins. *Rev. Met.,* 53, No. 2, 105-110; disc., 110 (1956) Feb.

Review of literature on intercrystalline stress-cracking of high-tensile β-brasses; detection, by electrolytic polishing methods, of grain boundary grooves in cast and heat-treated specimens of a ternary β-brass. Micrographs. 16 references.—BTR.   12414

6.3.6, 3.7.2

Effect of Very Small Contents of Tel-

lurium in Copper. (In German.) P. Klare. *Erzmetall,* 9, No. 8, 370-373 (1956) Aug.

Tests confirming the embrittling effect of tellurium on oxygen-containing copper in hot rolling. There is however a suggestion that there is a maximum content of tellurium, beyond which the behavior of the copper is improved owing to a grain-refining effect of the tellurium. Embrittling effect is ascribed to concentration of tellurium or its compounds at grain boundaries.—BNF.   12502

6.3.7, 3.7.4

Investigation of the Corrosion Resistance of Solid Solutions of Metals. Pt. I. The System Indium-Lead. (In Russian.) N. N. Gratsianskii and M. L. Kaplan. *J. Phys. Chem., USSR* (Zhur. Fiz. Khim.), 30, No. 3, 651-659 (1956) March.

In the case of low-melting solid solutions in which at room temperature the atoms possess a high diffusion velocity, a limit is observed to the corrosion resistance.—MR.   12464

6.3.8, 7.10, 4.3.2

Further Studies on the Anodic Corrosion of Lead in Sulfuric Acid Solutions. J. J. Lander. *J. Electrochem. Soc.,* 103, 1-8 (1956) January.

Interprets the thermodynamics and kinetics of the corrosion process in order to indicate means of preventing or slowing down corrosion, thus allowing longer positive grid life. Tables, graphs, diagram. 12 references.—BTR.   11372

6.3.8

The Corrosion of Lead in Sulfuric Acid as Influenced by the Structure of the Metal. (In Russian.) M. A. Dasoian. *Doklady Akad. Nauk. SSSR,* 107, No. 6, 863-866 (1956) June.

Experimental data on the mechanism of action of various anti-corrosion additives in lead. Tables, micrographs, photograph. 7 references.—BTR.   12392

6.3.8, 4.3.2

Anodization of Lead in Sulphuric Acid. Jeanne Burbank. *J. Electrochem. Soc.,* 103, No. 2, 87-91 (1956).

The anodic-corrosion product formed on lead in sulfuric acid solution depends on the potential of the metal surface. In the potential range between lead-lead sulfate and lead sulfate-lead dioxide, the following compounds were identified by electron diffraction: monobasic lead sulfate, lead hydroxide and lead mono-oxide. In addition, the diffraction pattern for an unidentified material was observed. Coordinated potential/time curves show arrests corresponding to the appearance of these compounds. The physical nature of these corrosion films is discussed. 14 references.—MA.   12378

6.3.8, 6.3.14, 2.2.2

The Use of Lead and Tin Outdoors. George O. Hiers and Elbert J. Minarcik. Paper from Symposium on Atmospheric Corrosion of Non-Ferrous Metals, ASTM Special Publication No. 175, 1956, 135-140. Available from: American Society for Testing Materials, 1916 Race Street, Philadelphia, Pa.

Corrosion penetration showed chemical lead and antimonial lead are remarkably durable in all of the test site exposures. Losses in strength can be compensated. —BTR.   12448

6.3.8, 6.3.11, 3.6.8, 3.8.4

Oxide Formation and Overvoltage of Oxygen on Lead and Silver Anodes in Alkaline Solution. P. Jones, H. R. Thirsk

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AND W. F. K. WYNNE-JONES. *Trans. Faraday Soc.*, **52**, No. 7, 1003-1011 (1956) July.

Study of anodic behavior of lead and silver in 1 N potassium hydroxide to determine nature of oxide layers formed and their influence on the measurement of oxygen overvoltage.—BNF.   12476

6.3.9, 3.5.9

Protecting Molybdenum from Oxidation. A. J. HERZIG AND J. R. BLANCHARD. Climax Molybdenum Co. *Metal Progress*, **68**, No. 4, 109-114 (1955) October.

Discusses cladding, electroplating, metal spraying and ceramic coatings for protection of molybdenum at temperatures above 1450F. Coatings attain their protective and refractory characteristics through diffusion of molybdenum into them and from internal formation of oxidation products. Coating compositions of chromium-silicon, chromium-molybdenum-silicon, molybdenum-nickel-silicon, iron-silicon and nickel-silicon, all mixed with aluminum for spraying and Colomonoy #5 and #6, and Coast Metals Alloy Mod. 50, sprayed without aluminum, are evaluated. All provide oxidation protection for 500 hours at 1800F. Tests included oxidation, thermal shock, ductility, ballistic impact and erosion tests. Table.—INCO.   11487

6.3.10, 3.7.2, 1.6

Investigation of the Effects of Incongruous Elements and the Interaction Effects of These Elements on High Temperature Strength of Iron-Cobalt-Nickel-Chromium Alloys. T. L. ROBERTSHAW AND F. M. RICHMOND. Universal-Cyclops Steel Corp. U. S. Wright Air Development Center, April, 1956, 62 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 121379).

An investigation was made of the effect of hardening elements (molybdenum, columbium, aluminum, titanium, boron, carbon and zirconium) on the high temperature properties of vacuum melted alloys with a base composition of 60 atomic percent nickel, 20 atomic percent chromium, 10 atomic percent cobalt, and 10 atomic percent iron. Stress rupture properties of these alloys at 1600 F were found to be dependent on the vacuum obtained during melting, the fabrication methods and the total amount of hardener. It was concluded that a higher level of strength was more likely to occur at a given hardener level when a greater variety of hardening elements were added.   12573

6.3.10, 4.2.3, 3.2.2

Contribution to the Knowledge of Modified Heat-Resistant 80-20 Nickel-Chromium Alloys. (In French.) M. MATHIEU. *Recherche Aeronaut.*, No. 51, 43-51 (1956) May-June.

An investigation of the causes of fracture of forged buckets. Evolution of structure under conditions of use; corrosion in air and combustion gases; effect of work-hardening on both structure and corrosion. Skin-annealing for protection against cracking corrosion. 29 references.—BNF.   12525

6.3.14

Creep of Polycrystalline Tin. J. E. BREEN AND J. WEERTMAN. *J. Metals* (Trans. A.I.M.E.), **7**, No. 11, Section 2, 1230-1234 (1955) Nov.

Creep rate studied as a function of temperature and stress in constant stress experiments from room temperature almost to the melting point.—BNF.   11330

6.3.15

Electrical Resistance Study of the Effects of Oxygen on the Allotropic Transformation of Titanium. L. A. DE-PUE AND E. J. CHAPIN. Naval Research Laboratory, February, 1956, 26 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 111741).

The allotropic transformation of eight titanium-oxygen alloys ranging from 0.028 to 2.7% was studied by determining their change of electrical resistance with temperature. All the alloys were prepared by arc fusion of high-purity titanium with pure titanium dioxide, except for one high-purity alloy which was not fused but prepared directly from the as-deposited condition by mechanical working. The resistance of the specimens was measured in vacuum by obtaining the voltage drop across a gage length of 1.75 inches, using a low current ranging from 51 to 91 milliamperes. This method of measuring the electrical resistance as a function of temperature was found to be a highly sensitive and reproducible means for continually following the progress of the allotropic transformation of titanium-oxygen alloys.
12393

6.3.15

The Cold Extrusion of Titanium. A. M. SABROFF AND P. D. FROST. Battelle Memorial Institute. U. S. Wright Air Development Center, February, 1956, 50 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 121267).

The methods of cold shaping of other metals were successfully applied to unalloyed titanium during preliminary experimentation. With an initial approach based on cold extrusion of steel, studies were conducted on two grades of unalloyed titanium to evaluate effects of die design and extrusion reduction. Forward extrusions with reductions of 40, 50 and 60 percent were accomplished on 3-inch billets with diameters of 1½ inches. A fluorine coating combined with an oil-graphite-molybdenum disulfide lubricant prevented seizing between the workpiece and the die and produced a good surface finish. Working pressures were comparable to those required for cold extrusion of steel. The extruded bars showed uniform deformation and work hardening.
12565

6.3.15, 3.7.2, 3.2.2, 1.6

The Effects of Interstitial Contaminants on the Notch-Tensile Properties of Titanium and Titanium Alloys. E. P. KLIER AND N. FEOLA. Syracuse University. U. S. Wright Air Development Center, March, 1956, 105 pp. Available from: Office of Technical Services, U. S. Department of Commerce, Washington, D. C. (Order PB 121335).

Notch-tensile properties of sponge titanium contaminated with oxygen, nitrogen and carbon were determined. Base oxygen content of the different materials were valued at about 0.035%. About 0.25% nitrogen can be tolerated at —65 and —100 F while at —320 F the maximum is about 0.20 percent. At —65 and —100 F about 0.40% carbon can be tolerated while at —320 only 0.3 can be allowed. Brittle behavior in the notch-tensile test of titanium melted from sponge and contaminated to maximum levels was observed at —320 F. Figures on embrittlement effectiveness of the contaminants indicate that large amounts of carbon and smaller amounts of nitrogen can be tolerated in titanium

with a base oxygen content of 0.035% without severe embrittlement even at —320 F. The presence of nitrogen in all oxygen alloys makes it difficult to determine the embrittling action of oxygen in the presence of nitrogen. Better behavior at higher testing temperatures is indicated and if notch tough titanium is to be obtained low oxygen levels must be maintained.
12487

6.3.15, 6.3.20, 3.6.6, 1.6

Galvanic Corrosion Properties of Titanium and Zirconium (Coupled with Other Metals) in Various Inorganic Solutions. D. SCHLAIN, C. B. KENAHAN AND D. V. STEELE. U. S. Dept. of Interior, Bureau of Mines, Rept. of Investigations No. 5201, April, 1956, 60 pp.

Behavior of couples of titanium and of zirconium with magnesium, magnesium alloy FSI, aluminum alloys, zinc, steel, tin, lead, copper, Monel, nickel and several stainless steels; in synthetic ocean water, tap water, 5% ammonium sulfate, 5.5% sodium chloride, sodium hydroxide, 0.1 N hydrochloric acid and several concentrations of sulfuric acid at 35 and 60 C.—BNF.
12568

6.3.20, 1.6

Some Investigations into Zirconium Alloy Systems. B. A. ROGERS AND P. CHIOTTI. Ames Lab. U. S. Atomic Energy Comm. Pubn., ISC-132, November 28, 1950 (Declassified January 6, 1956), 64 pp. Available from: Office of Technical Services, Washington, D. C.

A series of individual reports on the binary alloy systems of zirconium with aluminum, antimony, bismuth, carbon, copper, germanium, niobium, thorium, tin and uranium is presented. The available thermal, microscopic, x-ray-diffraction, hardness and corrosion data are given. Some qualitative data on corrosion of miscellaneous alloys with chromium, platinum, lead, vanadium and molybdenum is appended.—NSA. 12578

6.3.20, 1.6

Zirconium Alloy Corrosion Data Submitted to the Zirconium Alloy Corrosion Committee Meeting, May 17 and 18, 1954. STANLEY KASS. Westinghouse Elec. Corp. U. S. Atomic Energy Comm. Pubn., AECD-4017, Declassified January 14, 1956, 63 pp.

Numerous data on corrosion of Zircaloy-2, Zircaloy-3, and various zirconium-base alloys in 680 F water, 600 F hydrogenated water, 750 F steam, etc., are compiled. The effects of the various compositions and heat treatments are shown.—NSA. 12504

6.3.20, 3.5.9

An Investigation of Scaling of Zirconium at Elevated Temperatures (Quarterly Status Report No. 12 for March 2, 1956 to June 2, 1956). C. A. BARRETT, E. B. EVANS AND W. M. BALDWIN, JR. Case Inst. of Technology. U. S. Atomic Energy Comm. Pubn., AECU-3257, June 11, 1956, 4 pp. Available from: Office of Technical Services, Washington, D. C.

Scaling of zirconium at elevated temperatures in air was studied. Self-heating effects, hydrogen pickup and simulated scales were evaluated for their effect on the scaling.—NSA. 12404

6.3.20, 3.7.3

Effect of Heat Treatment on the Corrosion Behavior of Zirconium Binary Alloys of Nickel and Iron. D. S. KNEPPEL. Nuclear Metals, Inc. U. S. Atomic

Energy Commission Pubn., NMI-1137, June 22, 1955, 44 pp.

The effect of heat treatment on the corrosion resistance in 680 F water of zirconium binary alloy of iron and nickel was studied. Slow-cooling zirconium from beta phase tended to precipitate out the zirconium compounds of iron or nickel resulting in metal of poor corrosion resistance because of preferred attack of these compounds. In addition, it appears that stresses developed when zirconium transforms rapidly from beta to alpha, are also a cause of accelerated attack. Nickel in solid solution is very effective in inhibiting corrosion due to transformation stresses whereas iron is only mildly effective. (auth)—NSA.
11751

6.3.20, 4.6.1

Aqueous Corrosion of Zirconium and Its Alloys at Elevated Temperatures. D. E. THOMAS. Paper before International Conf. on Peaceful Uses of Atomic Energy, Geneva, August, 1955. United Nations Paper A/CONF. 8/P/537, August 1955, 16 pp.

Discussion of corrosion of unalloyed zirconium in high-temperature water including kinetics and effect of impurities (beneficial effects of iron, chromium and nickel when present at about 0.1%), corrosion of zirconium in steam and corrosion behavior of binary and higher alloys of zirconium, (zirconium-tin, zirconium-iron, zirconium-nickel, zirconium-chromium alloys). Nickel, when present above 0.5 wt% confers corrosion-resistance in steam at 400-816 C. It is superior to that of unalloyed zirconium, but has adverse effect on corrosion-resistance in hot water. Effects of alloying elements are additive. Extensive data on corrosion behavior of Zircaloy 2 (a sponge-base alloy permitting use of Kroll process zirconium sponge, developed by Westinghouse and containing 1.5 tin, 0.12 iron, 0.1 chromium, 0.05% nickel, 60 ppm max. nitrogen) in high-temperature water and steam are given. Mechanism of corrosion and application of corrosion data so far obtained to design of components are described. 11 references.—INCO. 11847

6.3.20, 3.7.3

The Welding of Zirconium. E. C. ROLLASON AND B. S. HOCKENHULL. *Welding and Metal Fabrication,* 24, No. 7, 230-234 (1956) July.

Argon arc welding of zirconium: the purity of the metal greatly affected weld ductility and the iron and oxygen contents should be as low as possible. DC welding is superior to AC. Results of bend, tensile and corrosion tests and metallographic examination are given. Surface absorption of oxygen during welding improved the corrosion resistance. Some work was also done on the welding of zirconium to stainless steel. —BNF. 12569

6.3.21, 2.6

Aqueous Corrosion of Thorium and Thorium Alloys. J. W. ARENDT, W. W. BINGER, J. HOPKINS AND F. NELSON. Chicago Univ. U. S. Atomic Energy Comm. Pubn., CT-3036, June 23, 1945 (Declassified January 4, 1956), 31 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C.

A study of the resistance to aqueous corrosion of extruded Ames thorium, a cast material and of extruded Westinghouse thorium, a material made by powder metallurgy, as well as of tho-

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rium alloys in "as cast" condition is reported. Samples were exposed in air-free, relatively pure water at temperatures of 100 and 178 C and also in a simulated river water with added hydrogen peroxide (0.006N) flowing at 20 to 25 ft/sec at a temperature of 70 C. It was necessary to devise a suitable method to remove the corrosion products without removing unaltered metal, in order to obtain accurate corrosion rates of thorium. The most satisfactory methods were treatment with 70 wt.% nitric acid saturated with sodium fluoride at room temperature, and anodizing in 10 wt.% sodium hydroxide at 30 to 34 C. (auth) —NSA.   12391

6.3.21, 3.5.9, 5.3.4

Protection of Thorium at Elevated Temperatures. Part I. Silver Plating for Short-Time Atmospheric Exposure at 700 C. R. T. OTHMER AND GLENN MURPHY. Ames Lab. U. S. Atomic Energy Comm. Pubn., ISC-214, April 10, 1952 (Declassified January 5, 1956), 8 pp. Available from: Office of Technical Services, Washington, D. C.

Silver plating was investigated as method of preventing corrosion of thorium at temperatures ranging from 300 to 700 C. Plating procedure and results of tensile and fatigue tests of plated specimens are discussed. Investigation of multiple coatings in order to improve protection is under investigation.—NSA.   12526

6.3.21, 3.8.4, 5.9.4

Anodic Film Growth on Hafnium in Nitric Acid. R. D. MISCH AND E. S. FISHER. *J. Electrochem. Soc.*, **103**, No. 3, 153-156 (1956) March.

In 70% nitric acid at room temperature, an anodic film developed uniformly over single hafnium crystals with a thickness dependent upon the metal crystal orientation. At 0.025 ma/cm² the cell voltage did not exceed 1.5 v; at 1.5 ma/cm² the cell voltage rose to 185 v and the film was broken down by sparking. At 90 C and 0.025 ma/cm², the oxide developed discontinuously over hafnium crystals with the formation of wedge like patches. This discontinuous growth was attributed to nucleation at metal surface imperfections. An orientation effect in the electropolishing of hafnium was also noted. (auth).—NSA.   12520

6.4 Non-Ferrous Metals and Alloys—Light

6.4.2

Unidal (Aluminum-4.5 Zinc-1 Magnesium). (In French and German.) H. HUG. *Aluminium Suisse*, **5**, No. 4, 112-121 (1955) July.

Composition, physical and mechanical properties, heat treatment, plastic deformation, welding, chemical and anodic oxidation, corrosion properties and application of Unidal are discussed. —BNF.   10944

6.4.2, 3.2.2

The Pitting of an Aluminium Porringer by Copper-Contaminated Water. J. M. BRYAN. *J. Sci. Food and Agr.*, **6**, 305-311 (1955) June.

Rapid corrosion of aluminum was found to be due to contamination of water by copper: use of metallic scourers containing copper can also cause severe pitting. The pitting was not serious in the absence of salt. It is suggested that Nylon scourers be substituted for brass or copper.—BNF.   11927

6.4.2

A Review of Aluminium Alloys as Engineering Materials. J. R. HANDFORTH. *Welding*, **23**, No. 6, 204-210 (1955).

Handforth classifies aluminum alloys into four groups: 1) low-strength alloys, e.g. S1B and NS3; 2) medium-strength alloys, e.g. NS4-7 and HS10; 3) Duralumin and Super-Duralumin; and 4) high-strength alloys, e.g. D.T.D. 687. The heat-treatment, corrosion-resistance, fabrication and welding of these alloys and examples of their applications are reviewed.—MA.   11804

6.4.2

Die Forging and Forming Aluminium Alloys. (In French.) ROBERT COLOMB. *Rev. Aluminium*, **33**, No. 229, 162-167 (1956) Feb.

In this concluding part of a series of articles on aluminum alloy forgings the aims and methods of dimensional and quality control before and after heat treatment are discussed and the tolerances are tabulated. Some practical information concerning corrosion protection and machining of forgings is also presented.—ALL.   12407

6.4.2

Sealing of Holes in Aluminum Sheet by Oxidation. S. ANDERSON AND N. GOLDOWSKI. Chicago Univ. U. S. Atomic Energy Comm. Pubn., CP-1837, July 15, 1944 (Declassified January 5, 1956), 30 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C.

An investigation is made of the conditions under which holes in aluminum may be expected to close by oxidation while in use in reactors. A brief theoretical discussion is given of the mechanism of oxidation of aluminum. Preliminary experimental results on plugging by chemical oxidation and by corrosion are summarized. It is concluded that under the most favorable conditions, only small holes may be sealed by oxidation processes.—NSA.   12421

6.4.2, 2.2.2

Effect of 20-Year Marine Atmosphere Exposure on Some Aluminum Alloys. F. M. REINHART AND G. A. ELLINGER. Paper before ASTM, 58th Ann. Mtg., Symp. on Atmospheric Corrosion of Non-Ferrous Metals, Atlantic City, June 29, 1955. Am. Soc. Testing Materials Special Technical Publication No. 175, 1956, 47-64; disc., 65-66; Summary: *Nat'l. Bureau of Standards Tech. News Bull.*, **40**, No. 1, 13-15 (1956) Jan.

Corrosion data on specimens of commercially available structural aluminum alloys and some experimental alloys exposed for long-time weather tests in 1932 at Coco Solo, Canal Zone, Norfolk, Va. and Washington, D. C. All of the non-heat-treatable alloys containing < 4 magnesium and one with 1 manganese were very resistant to corrosion. Of heat treatable alloys, clad varieties and one alloyed with 2 cadmium were quite corrosion resistant, while those containing copper, silicon and manganese were least resistant. Aluminum-copper alloys were susceptible to intergranular corrosion and rapid disintegration when improperly quenched or artificially aged unless adequately protected. Effects of various surface treatments and protective paints were noted. Anodically formed films gave more protection than films from chemical immersion. Most protective paints were those pigmented with zinc chromate and aluminum powder. Nicarlium, an aluminum alloy containing 0.01 nickel, 0.17 molybdenum, 0.18 zinc and 0.08 tungsten, was among alloys tested. Tables, graphs.—INCO.   12555

6.4.2, 3.2.3, 5.4.2

Natural and Thermally Formed Oxide Films on Aluminum. M. S. HUNTER AND P. FOWLE. *J. Electrochem. Soc.*, **103**, 482-485 (1956) Sept.

Structure and rate of formation of natural and thermally formed oxide films on aluminum are discussed. It is shown that these films consist of a layer of barrier-type oxide, the thickness of which is primarily a function of temperature and a porous layer, the thickness of which is determined by time and natural forces associated with the environment. Effects of temperature and environment on the formation rate and ultimate thickness of these layers are described.   12498

6.4.2, 3.5.8

The Stress-Corrosion of Certain Aluminium Alloys. H. K. FARMERY AND U. R. EVANS. *J. Inst. Metals* (England), **84**, Pt. 11, 413-422 (1956) July.

Stress-corrosion cracking of sheet material in salt solution is favored: 1) by removal of the as-rolled film from aluminum-7% magnesium alloy in aluminum chloride solution or of that from aluminum-4% copper alloy in sodium hydroxide solution, and 2) by addition of sodium bicarbonate to the salt solution, which prevents the weak anodic acidity being swamped by the strong cathodic alkalinity; the stress-corrosion life is greatly affected by previous heat-treatment. If the exposed area is made small, life is usually increased, but electrical connection to a large unstressed area may shorten the life of the 7% magnesium alloy; the current flowing in a "differential stress cell" between a stressed 7% magnesium alloy specimen as anode and an unstressed one as cathode, increases with the magnitude of the stress applied. Junction of the small stressed alloy specimen to a noble metal such as copper greatly shortens the life. The absence of conspicuous corrosion product and the bright fracture suggest that the total amount of chemical action is not large, but chemical change affecting only a small amount of intergranular matter may suffice to replace plastic deformation within the grains by intergranular rupture. (auth)—ALL.   12459

6.4.2, 4.6.1

Aqueous Corrosion of Aluminum. Pt. 2. Methods of Protection Above 200 C. J. E. DRALEY AND W. E. RUTHER. *Corrosion*, **12**, No. 10, 480t-490t (1956) Oct.

At elevated temperatures most aluminum alloys in water suffer severe penetrating attack, resulting in their relatively rapid destruction. This penetrating attack is explained in terms of mechanical damage as a result of diffusion of corrosion-product hydrogen into the metal.

It is prevented by adding to the water cations which are reduced on the aluminum to form deposits of low hydrogen overvoltage metals. It is also prevented in untreated water by using aluminum alloyed with the same metals. Alloying metals observed to be beneficial are nickel, copper, cobalt, iron

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and platinum, with nickel probably the most effective.

There has been developed an alloy, containing approximately 1% nickel in 1100 aluminum, which appears to be completely safe against the penetrating attack up to 350 C. It is easy to make and is workable. It probably can be used, from a corrosion-resistant point of view, wherever its normal reaction rate with water or a solution is tolerable. Penetration rates in static distilled water range from approximately 0.5 mg/dm²-day at 150 C to 18 mdd at 350 C (0.3 to 9 mils per year). They are higher where there is significant flow velocity of water past metal. 12353

6.4.2, 4.6.2
High Temperature Aqueous Corrosion of Commercial Aluminum Alloys. R. L. DILLON, R. E. WILSON AND V. H. TROUTNER. Hanford Atomic Products Operation. U. S. Atomic Energy Comm. Pubn., HW-37636, Jan. 11, 1956, 14 pp. Available from: Office of Technical Services, Washington, D. C.

The corrosion resistance of some 50 commercial aluminum alloys has been investigated in high temperature distilled water. From static autoclaves conducted at 250, 305 and 350 C, the aluminum-nickel, aluminum-silicon, aluminum-copper-nickel and aluminum-magnesium-silicon alloys have been shown to be most corrosion resistant. In cases of rapid failure the attack is intergranular. The more resistant alloys all contain significant amounts of copper, nickel or silicon. (auth)--NSA. 12409

6.4.2, 4.6.2, 3.7.2
The Attack of Water on High Purity Aluminum at Elevated Temperatures; Observations Made on the Mechanisms. (In French.) JEAN HERENGUEL AND PIERRE LELONG. Compt. Rend., 242, No. 25, 2941-2944 (1956) June 18.

Electrolytically or chemically polished samples of high purity aluminum were subjected to the corrosive attack of water at 165 and 205 C. Three distinct processes were observed: 1) formation of a homogeneous and continuous protective film, approximately 12 μ thick; 2) intergranular penetration into said film; 3) pitting at the metal/film interface competing with the aforementioned phenomena and gradually replacing effect 1). The kinetics of these processes are diagrammatically represented. Dimensional changes of the sample due to the effects described are scrutinized and it is said that information thus obtained may permit the evaluation and classification of the various alloying additions which are thought to increase the resistance of aluminum to water at elevated temperatures.—ALL. 12465

6.4.3, 3.5.9, 3.4.6
The Reaction of Beryllium with Carbon Dioxide in the Temperature Range 500-700 C. W. MUNRO AND J. WILLIAMS. Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England, February, 1956, 16 pp.

The corrosion of dense beryllium in wet and dry carbon dioxide at atmospheric pressure has been investigated for the temperature range 500 to 700 C. At 500 C the corrosion rate in both wet and dry gas is negligible; at 600 C the corrosion product film is protective in the dry but not the wet gas; at 650 and 700 C the surface film is no longer protective even in the dry gas. Comparison of the weight gains in dry oxygen and dry carbon dioxide suggests that beryllium carbide formation may become significant at 650 C and make the oxide film non-protective. (auth).—NSA. 12519

6.4.3, 3.8.4, 3.5.9, 3.7.4
The Structure and Growth of Oxide Layers Formed on Beryllium. I. S. KERR AND H. WILMAN. J. Inst. Metals, 84, Pt. 10, 379-382; disc., 383-384 (1956) June.

An electron-diffraction study of oxide layers on beryllium has established that on polycrystalline metal surfaces at 300 C and over, the oxide developed in a one-degree orientation which varied with the temperature of formation. On abraded beryllium below 700 C, the beryllium oxide grew in the (001) orientation, but above 700 C in (100). The oxide formed on smooth, electro-polished, coarsely crystalline beryllium at temperatures up to 250 C had a grain-size of about 10 Å, but that formed at 300 C and above measured 60 Å or more, with preferred (001) orientation up to 700 C. Growth of the oxide in air at room temperature was not increased by irradiation with ultra-violet light. On vacuum-deposited beryllium surfaces, the oxide grew epitaxially on the exposed (001) and (110) metal faces, even though at room temperature the grain-size of the oxide crystals was only about 10 Å. This striking case of epitaxy under conditions of extremely limited surface mobility was thus observed at a stage only a little beyond that at which the initial nuclei originate from chemisorption. Anodic beryllium oxide layers, formed in a nitric-chromic acid solu-

tion, grew at a constant rate up to several thousand Å thickness, with a linear current/voltage relationship. The initial very thin beryllium oxide layers were amorphous, but on reaching a thickness of 100-150 Å and subsequently, the surface consisted of dandomly disposed beryllium oxide crystals, 60 Å or more in diameter, indicating that in this and similar cases the surface temperature of the growing deposit considerably exceeds 300 C. (auth)—MA.   12559

6.4.4, 3.6.8, 3.2.2

Effect of Anodic and Cathodic Polarization on the Susceptibility of Alloy MA-3 (Magnesium Alloy) to Corrosion Cracking in a Solution of 35 g/l Sodium Chloride + 20 g/l Potassium Chromate. V. V. ROMANOV. *J. Applied Chem., USSR* (Zhur. Priklad. Khim.), **29**, No. 8, 1191-1196 (1956).

Anodic polarization was found to increase susceptibility; cathodic, to decrease it. Two tables, 5 figures, 5 references.—ATS. Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.   12562

6.4.4, 3.7.2

Experimental Magnesium Alloys Containing Nickel, Manganese, Lithium and Aluminum. J. A. ROWLAND, C. E. ARMANTROUT and D. F. WALSH. U. S. Dept. of Interior, Bur. of Mines, Report of Investigations No. 5250, July, 1956, 21 pp.

Investigation of properties and fabrication of magnesium alloys containing nickel, nickel and manganese, lithium, lithium and manganese and lithium and aluminum. Magnesium-nickel and magnesium-nickel-manganese alloys failed to develop superior mechanical properties and were very low in resistance to corrosion. Magnesium-lithium series, although entirely plastic, had low strength properties. Addition of small amounts of aluminum to the magnesium-lithium base did not affect greatly either the ductility or the strength. Photomicrographs, graphs.—INCO.   12582

6.6 Non-Metallic Materials

6.6.5, 5.4.5

Concrete Coating Materials. Detailed Project Status Report. Job. 11. Kellex Corp. U. S. Atomic Energy Comm. Pubn., KLX-71, Sept. 23, 1949 (Declassified January 10, 1956), 13 pp. Available from: Office of Technical Services, Washington, D. C.

Industrial vinyl copolymer resin paints were found to provide satisfactory waterproof coatings for the concrete walls. They were found to have sufficient corrosion resistance to warrant their consideration for other applications, especially since they are less expensive and are easier to prepare than flame sprayed plastics.—NSA.   12478

6.6.5, 6.6.6

Chemical- and Corrosion-Resistant Floors. B. MOHR. *Corrosion Technology,* **3,** No. 7, 227-231 (1956) July.

Types of corrosion-resistant flooring discussed include acid-resisting asphalt mastic, rubber latex/hydraulic cement mixtures, membranes (impervious underlayers), acid- and chemical-resisting brick, and acid- and alkali-resisting mortars (silicate cement, sulfur cement, bituminous cement and resin in mortars).—INCO.   12522

7. EQUIPMENT

7.1 Engines, Bearings and Turbines

7.1

Corrosion of the Cylinders of Automobile and Tractor Engines. (In Russian.) B. B. GENBOM. *Avtomobil'naya i Traktornaya Promyshlennost',* No. 5, 18-23 (1956) May.

Temperature of combustion of fuels and other conditions controlling electrochemical corrosion of cylinders. Uneven distribution of temperature on cylinder surfaces as a cause of uneven wear. Effect of variation in engine's cooling system.—BTR.   12458

7.2 Valves, Pipes and Meters

7.2, 5.4.2

Intrinsic Protection of Water Mains. M. UNZ. *Corrosion,* **12,** No. 10, 526t-532t (1956) October.

Inherent protection against corrosion hazards is essential in water supply systems. External corrosion is reduced by the use of cement coatings and separation of heterogeneous line sections. Internal galvanic action, especially in prestressed concrete structures, is eliminated by separation or matching of materials. A complete solution of the problem is atained only by electrically nonconducting pipe. Internal corrosion and blocking of pipes can be prevented by water treatment.

Investigations on an irrigation system confirm that bare or bituminous coated steel components are anodic to cement coated lines. Irrigation outlets during the dry season also usually are anodic to the trunk line. In anodic areas a chemical absorption process takes place in the cement coating, which intrinsically increases its protective value. The presence of an adequate layer of pure cement over the steel surface is essential for this protective effect.   12357

7.4 Heat Exchangers

7.4.2

Design, Operation and Maintenance of Marine Surface Condensers. J. F. SEBALD. Worthington Corp. *Mariner,* **4,** Nos. 4, 5, 6, 8, 14, 48, 51; 18-19, 36-37, 40-41; 14-15, 64, 66; 18-19, 44-47, 54-56 (1956) April, May, June, August.

Corrosion resistance to condenser circulating water is a major factor in selecting condenser tube materials for merchant ships. Aluminum brass and aluminum bronze are generally satisfactory for sea water but when a high degree of dependability is involved, copper-nickel condenser tubes are used. Modern marine type steam condensers are built with water chests made from copper base alloys or from steel. Copper alloy water chests are protected from salt water corrosion by lining with tin. Water chests made of ferrous materials are protected by application of synthetic rubber coatings or plastic paints. Water chests made of ferrous materials protected from electrolytic corrosion by use of sacrificial metals, zinc or magnesium, installed in the water space. Cleaning of fouled condenser tubes by wire brushing and rodding is discussed. Illustrations.—INCO.   12585

7.4.2, 6.3.6, 4.6.2, 4.6.4

Corrosion, Cracking and Erosion on the Outer Surfaces of Copper Alloy Condenser Tubes. Pt. I. (In German.) F. W. NOTHING. *Metall,* **10,** No. 11/12, 520-523 (1956) June.

Begins with a table setting out materials used in Germany as condenser tubes and heat exchangers (64/36 copper/zinc; arsenical or non-arsenical 70/30 copper/zinc; arsenical 70/29/1 copper/zinc/tin; arsenical aluminum brass; copper/nickel/iron, 10/20/30 nickel; arsenical copper/aluminum 95/5; arsenical copper; phosphorized copper: for arsenical brass, and/or phosphorus is quoted). Corrosion by condensates or cooling media, with general or pitting corrosion, a number of practical examples marine and other being quoted.—BNF.   12517

7.5 Containers

7.5.2, 5.3.2, 8.3.5

Observations on the Internal Corrosion of Tin-Plate Cans by Acid Foodstuffs. H. CHEFTEL, J. MONVOISIN and MALWINA SWIRSKI. *J. Sci. Food and Agriculture,* **6,** 652-655 (1955) November.

It is shown that the anodic behavior of tin vs iron in the corrosion of tin plate by canned foods is what would be expected on theoretical grounds. With reference to the fact that the hydrogen evolved during the corrosion of tin plate is less than the amount corresponding to the metals dissolved, an electrochemical mechanism is suggested which may account in part for this deficit. Attention is also drawn to previously unsuspected accelerators of corrosion, e.g. caramelization products in fruits. Tables. 12 references.—BTR.   11377

7.6 Unit Process Equipment

7.6.4

An Investigation into the Air-Heater Corrosion of Oil-Fired Boilers. B. LEES. *J. Inst. Fuel,* **29,** 171-175 (1956) April; *Combustion,* **28,** 38-42 (1956) July.

Methods which have been successfully applied to reduce the fouling and wastage are described. Future experiments to ascertain optimum operating conditions, and the most suitable air-heater design are also considered. Diagrams, graphs, table. 3 references.—BTR.   12490

7.6.5, 4.3.6, 4.6.10

Corrosion Experience with a Modern Salt Evaporator. R. B. RICHARDS. Paper before Am. Inst. Chem. Engrs., 48th Ann. Mtg., Detroit. *Chem. Eng. Progress,* **52,** No. 6, 58, 62 (1956) June.

When test pieces of Types 304, 316 and 347 showed minor pitting and roughening after three months in salt evaporator while Monel test piece appeared untouched and was covered with thin carbonate scale, corroded pans were replaced with pans constructed of solid Monel. In heater, tube sheets are of Monel and tubes are 90-10 copper-nickel. Steel pipes are used for brine in general while plastic sections are inserted in lines to new pans. Tube failures occurred when small holes corroded through tubes just above bottom tube sheet. This type of corrosion was caused by insufficient rolling of the tubes. Evaporator history and construction of present day equipment are described.—INCO.   12577

GA

7.6.6

First Report—Regional Digester Activity. C. W. SMITH. Paper before Am. Pulp and Paper Inst., 10th Eng. Conf., Houston, November 7-9, 1955. *Tappi*, **39**, No. 5, 340-342 (1956) May.

Results of corrosion digester data from 13 mills showed that the average current corrosion rate of digesters has increased. Average rate on 84 carbon steel digesters ranged from 0 to 0.134 ipy and for Inconel-clad digesters the rates ranged from 0 to 0.051 ipy. Conclusion was that more time and care must be spent in trying to determine the cause of corrosion in the criti-

cal area for better evaluation of corrosion data. Reference is made to corrosion control in mills. Table.—INCO.
12514

7.7 Electrical—Telephone and Radio

7.7
Corrosion as It Affects Insulator and Conductor Hardware. A. W. BARDEEN AND J. M. SHEADEL. *Trans. Am. Inst. Elec. Engrs.* (Power Apparatus and Systems), **75**, No. 24, 491-498; disc., 498-501 (1956) June.

The different types of corrosion observed on insulators and hardware of power lines are described and classified; remedial measures are suggested. Tables, graphs, photographs. 8 references.—BTR.
12388

7.7, 8.4.3
Don't Short Circuit Your Offshore Operation. O. E. LUNDELIUS, JR. *World*

Oil, **142**, No. 7, 226, 230, 232, 234, 236, 238 (1956) June.

Development of offshore oil and gas resources gave rise to new engineering practices in electrical installation corrosion prevention. Every structure faces certain common problems relative to the electrical system, the more important being severe salt atmosphere corrosion and potential hazardous concentrations of flammable gas and vapor. Electrical system on offshore production platforms is described. Laboratory tests of cast fittings and enclosures made of highly refined copper-free aluminum alloy indicate a high resistance to sea water corrosion. Alloy for equipment must be free of copper and small parts should be of aluminum or stainless steel. Illustrations.—INCO.
12501

8. INDUSTRIES

8.1 Group 1

8.1.4
Corrosion and Materials in the Water Works Field. R. W. HENKE. *Water and Sewage Works*, **102**, 508-510 (1955) Dec.
Discussion of several factors involved in metallic corrosion, as a guide to combatting the condition. Diagrams, table.—BTR.
11488

8.4 Group 4

8.4.3, 3.2.2
Effect of Sulfides Scales on Catalytic Reforming and Cracking Units. Part 1. Metallographic Examination of Samples from a Catalytic Reforming Unit. Part 2. Intergranular Corrosion of 18-8 Chromium-Nickel Steel as a Result of Hydrolysis of Iron Sulfide Scale. E. L. HILDEBRAND. (A Contribution to the Work of NACE T-5B-2 on Sulfide Corrosion at High Pressures and Temperatures in the Petroleum Industry, M. E. Holmberg, chairman.) *Corrosion*, **12**, No. 10, 73-76 (1956) October.

Part 1. Carbon steel corrosion downstream from first reactor of catalytic reforming unit showed unusual intergranular sulfide penetration. 1% chromium—$\frac{1}{2}$% molybdenum plate steel from first effluent exchanger handling reactor effluent showed heavy corrosion damage. A theory of attack by hydrogen sulfide-hydrogen is postulated: Hydrogen gas penetrates, attacks iron carbide in pearlitic phase, resulting in decarburization. Methane gas formed from decarburization creates small intergranular rifts. Hydrogen sulfide gas enters voids and sulfidation of ferrite grains begins. Corrosion products force grains out of surface layer. Greater area thus created adds to corrosion rate. High temperature hydrogen sulfide-hydrogen corrosion is an intergranular progression.

Part 2. A fluid catalytic cracking unit which went into operation in 1942 suffered failure of 18-8 chromium-nickel steel lines from intergranular corrosion. Camp and Phillips showed this was due to action of moist sulfide scale during downtime. A spent catalyst hopper and stripper lined with reinforced castable refractory after some 50 cracks were found in a scheduled downtime, was found to be cracked around virtually every welding stud and scab patch. This Type 347 columbium-stabilized

stainless steel had both intergranular and transcrystalline cracks. A procedure is recommended to prevent sulfide scale hydrolysis corrosion from attacking 18-8 furnace tubes. This involves filling tubes with oil or oxygen-free steam or filling tubes with a weak alkaline solution during downtime.
12339

8.4.3, 4.4.6
Corrosion Problems in Oil Refining. R. M. ROBB. Paper before Australian Inst. Metals, Sydney Branch, August, 1955. *Australasian Engr.*, **1956**, 48-53, April 7.

Deals with corrosion resulting from petroleum products only and outlines basic mechanisms of corrosion from this source. Metal-gas, metal-liquid and 2-phase reactions are considered. Metallurgical factors influencing corrosion rates, corrosive media in petroleum, process technology, evaluation of corrosion rates, determination of corrosion pattern and design and economy are discussed. Linings of metal, concrete and plastic, organic inhibitors and elimination of corrodents are considered under corrosion mitigation.—INCO.
12571

8.4.3, 5.2.2
Casing Corrosion in the Hugoton Gas Field. W. C. KOGER. *Corrosion*, **12**, No. 10, 507t-512t (1956) October.

A casing leak survey in the Hugoton Gas Field was made to obtain information with which the casing corrosion problem could be evaluated and the most severely affected areas located. It was determined that leak frequency was relatively low but that leaks usually resulted in decreased deliverability or loss of the well. Because the pool is expected to be productive for another thirty years, the seriousness of the problem was not reflected entirely by current leak frequency.

Work to date indicates current application based on indications derived from surface potential measurements is sufficient to protect the wells and that the required current is obtainable from galvanic anodes. This latter fact is important because each well is located in the center of a section.

Interference from rectifier installations has been found in the field, presenting a new problem in efforts to protect casing cathodically from corrosion.
12351

8.4.5, 1.6, 4.7
Nuclear Metallurgy: A Symposium on Behavior of Materials in Reactor Environment Held on 20 February 1956. I.M.D. Special Report Series No. 2, 1956, 94 pp. Available from: Am. Inst. Mining Metallurgical Engineers, 29 West 39th Street, New York 18, New York.

Contents: R. C. Dalzell, General Problems in the Application of Materials in Reactor Environments; D. H. Gurinsky, The Behavior of Materials in Aggressive Liquid Metals; R. F. Koenig and E. G. Brush, Behavior of Materials in Non-Aggressive Liquid Metals; J. E. Draley and S. Greenberg, The Application of Materials in Low-Temperature-Water and Organic-Liquid-Cooled Reactors; D. M. Wroughton and D. J. DePaul, Structural Materials for Use in the Pressurized Water Power Reactor; G. P. Smith, Corrosion of Materials in Fused Hydroxides.—MA.
12399

8.4.5, 6.2.3
Operation of NRL-1 Carbon Steel Loop at the Materials Test Reactor. V. J. LINNENBOM and others. Naval Research Laboratory, August, 1956, 30 pp. Available from: Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB121319).

A low carbon steel loop was tested in an in-pile run as a possible substitute for loops of stainless steel used as primary coolants in pressurized water reactor systems. From the standpoint of deposition of corrosion products on exposed element surfaces, water purification data and the accessibility as determined by the various radioactive species within the system, carbon steel exhibited no serious disadvantages compared to stainless steel. There was no increase in corrosion due to radiation. Stress corrosion and effects of hydrogen embrittlement remain to be investigated.
12495

8.7 Group 7

8.7.2, 7.7
Choosing Materials for Instrument Manufacture—Importance of Correct Choice for Sensitive Mechanisms. P. MABB. *Corrosion Technology*, **3**, No. 7, 217-220, 232 (1956) July.

Light electrical apparatus may become corroded to slight degree not readily visible. No matter how effectively an instrument or equipment may be sealed hermetically, absence of corrosion depends on purity of materials used, processes to which parts were subjected, standard of finish and nature of protective coatings. Textiles as corrosion sources, insulating papers, moldings, bimetallic junctions, electroplating, welding, soldering and brazing and adhesive tapes are considered.—INCO.
12508

8.8 Group 8

8.8.1, 2.2.2, 5.1
Corrosion Problems on the Texas Gulf Coast. Parts I, II. A. D. RUST. Dow Chemical Co. *Corrosion Technology*, **3**, Nos. 5, 6, 134-137, 185-190 (1956) May, June.

Discusses corrosion as encountered at 2 plants of the Dow Chemical Co., Freeport, Texas. Plants produce organic products, plastics, magnesium, bromine, chlorine and caustic soda and are located on coastal plain of Gulf of Mexico where climatic, physiographical and industrial conditions make corrosion control imperative. Painting of various structures, preparation for painting and economies resulting from painting are considered. Test program of paint and metal samples exposed to seaside atmosphere corrosion is discussed (photo shows test panel racks). Roofing is of corrugated asbestos sheets which eliminates problem of metal roof corrosion. Dowicide is used to treat wooden structures and piling. Several miles of sheet steel piling exposed to atmosphere are protected with Bitumastic coatings while piling areas exposed to soil and sea water are cathodically protected with magnesium anodes. Corrosion does take place at tide-water line. Piping, pumps and screens for sea water are described. Pipes are lined with coal tar or Saran. Cathodic

protection of piling, pumps, heat exchangers, pipelines (outside), sea water pipes, condensers of power plant, tanks, tugs, barges and ocean-going vessels is reviewed. Condenser tubes are aluminum-brass.—INCO.
12567

8.8.1, 4.3.2
Corrosion in Sulfuric Acid Solution Containing Nitrogen Trioxide. H. ENDO AND G. YOKOYAMA. *J. Japan Inst. Metals*, **20**, No. 1, 42-46 (1956) Jan.

The corrosion of iron employed for the construction of tower system sulfuric acid manufacturing plants was investigated. Of the many corrosion processes coming forth in the process, the results tested under the conditions of 65-85% sulfuric acid, 0-300 g/l nitrogen trioxide and 40-120 degrees were described in this paper.—JSPS.
12413

8.8.1, 4.3.2, 4.3.3
Corrosion and Construction Problems of Sulphuric Acid Plant. G. C. LOWRISON AND F. HEPPENSTALL. *Corrosion Technology*, **3**, No. 6, 174-180 (1956) June.

Materials of construction considered from points of view of handling and storage of raw materials; preparation and burning; transport and cleaning of sulfur dioxide; conversion to sulfur trioxide; absorption; sulfuric acid cooling, storage and transport; concentration of acid.—BNF.
12500

8.8.1, 4.3.4
Managing Liquid Fertilizer Plant. *J. Agr. & Food Chem.*, **4**, No. 6, 502-507 (1956) June.

Discussion of liquid fertilizer plant construction. Neither aluminum rigs used for nitrogen solutions nor equipment used for weed killers are satisfactory. Stainless steel is widely used to guard against corrosion. Rig consists of a mild steel tank with stainless steel booms. Valves, meters, mixing tank and agitator are stainless steel. Aqua is reacted continuously with phosphoric acid in a small stainless steel vessel. Illustrations.—INCO.
12507

8.9 Group 9

8.9.3
Statement on Minimum Requirements for Protection of Buried Pipe Lines. Prepared by a Special Task Group of NACE Technical Group Committee T-2 on Pipe Line Corrosion. W. H. Stewart, Chairman. *Corrosion*, **12**, No. 10, 479t (1956) October.

A statement on Minimum Requirements for Protection of Buried Pipe Lines was prepared by a special task group of NACE Technical Group Committee T-2 on Pipe Line Corrosion. The statement reads as follows: 1) All underground steel piping should be coated with a protective material of permanent high electrical resistivity. Such coatings, if not so compounded as to resist soil stresses, shall be shielded in such manner as to receive negligible damage from such stresses. 2) The coated piping shall be further protected from external corrosion by supplementing the protective coating mentioned in 1) with adequate cathodic protection.
12361

8.9.3, 5.2.3, 5.4.10
Submarine Lines Need Corrosion Protection. R. C. LEDFORD. Marine Gathering Co. *Petroleum Engr.*, **28**, No. 6, D41-D43, D46 (1956) June.

To provide insulation of the metal

INDEX TO ADVERTISERS

of a gas and distillate production line from sea-water corrosion, a double coating of coal tar enamel, using glass fabric underneath with a second wrap of glass felt, was placed on the pipe. Line was buried 3 ft. under the Gulf floor by jet trenching to protect coating from organic attack. To provide for ultimate protection in case of deterioration of the coating over a long period of exposure and possibility of damage sustained by the coating, cathodic protection was installed on the line. Rectifiers were installed at platforms to impress sufficient current at that point to carry protective potentials all the way to the shore.—INCO.   12493

8.9.3, 5.4.5

Pipe Line Coating Practices. ALEX McCLURE. *Pipe Line News,* **28**, 41-42, 44-47 (1956) June.

Some factors associated with the selection and application of pipeline coatings; cost summary.—BTR.   12486

8.9.5, 6.4.2

Corrosion Problems Arising from the Use of Aluminum Alloys in H. M. Ships. Pt. I. J. C. KINGCOME. *Corrosion Prevention & Control,* **3**, No. 6, 31-34 (1956) June.

Aluminum alloys are being used in positions such as portions of bridge structures, bulkheads, decks, framing and internal structures, machinery space ladders and gratings. Natural resistance to corrosion of aluminum is reviewed. Alloys commonly used are NP5/6 containing 3.5-5.5 magnesium (for ships' plating), NE6 containing 4.5-5.5 magnesium or HE10 with 0.6-1.3 silicon (for sections), NR5 or NR6 containing 3-5.5 magnesium (for rivets), and LM6 with 10-13 silicon (for castings). Galvanic attack at aluminum to steel joints, at aluminum to copper joints and by paint containing compounds of lead, copper or mercury is discussed. Zinc chromate primer prevents corrosion by paint. With adaptation of cathodic protection to aluminum alloys, it should be possible to use copper-containing aluminum alloys and benefit from their superior mechanical properties.—INCO.   12485

8.9.3, 7.10

Longest Offshore Pipe Line Goes Into Operation. R. H. ILLINGWORTH, W. L. MONTGOMERY, C. ALDRIDGE AND C. V. TEMPLE. *Heating, Piping, Air Conditioning,* **28**, No. 7, 89-93 (1956) July.

Description of design and installation of off-shore pipe line facilities which move 12,000 bbl of oil and 10.5 million cu. ft. of gas daily from below Gulf of Mexico to a separation-distribution terminal 48 miles away. Insulated and coated with reinforced concrete, the 12 in. welded steel pipe line is buried below the silt line. Prefab pipe sections of wrought iron protect three-pile dolphins against corrosion of salt water and air in the highly corrosive zone a few feet above and below sea level. Living quarters platform is supported by steel caissons protected against corrosion by an 8 ft. high sheath of Monel in tide zone.—INCO.   12477

8.9.4, 5.4.3

Control of Contamination and Corrosion in Rail Tank Cars. S. JOHN OECHSLE, JR. AND KENNETH G. LE FEVRE. *Flow,* **11**, 94 + 7 pages (1956) August.

Types of protective linings and coatings, preparation of tank car for lining application, application process.—MR.   12554

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